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THE OCEANOGRAPHIC/METEOROLOGICAL ENVIRONMENT WEST OF ST. CROIX,(U)
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THE OCEANOGRAPHIC/METEOROLOGICAL ENVIRONMENT WEST OF ST. CROIX,

(10) D. A. BURNS

PHYSICAL OCEANOGRAPHY DIVISION

NAVAL OCEANOGRAPHIC LABORATORY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A review of oceanographic and meteorological data was undertaken for the underwater tracking range west of St. Croix in order to assemble a scenario of the physical environment. Recent current meter data from three current meter arrays moored during February 1976 indicated that the most significant contributions to the time-dependent flow are rotary motions that have maximum amplitudes coinciding with the semidiurnal tidal period (12.42 hours). Maximum horizontal current shear (1.2

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cm/sec/m)

centimeters per second per meter) occurs at about 100 ~~meters~~ m. Convective mixing appears to be the principal process of layer depth variation, which varied from a minimum of 50 meters during August to a maximum of about 120 meters during March. Surface winds are out of the east during all months, with speeds averaging from 10.4 knots in October to 14.0 knots in July. Maximum average wave heights (sea and swell) most frequently occur with periods between 10-11 seconds. Seasonal variation in sound velocity amounts to about ~~3 meters per second~~ in the first 100 ~~meters~~ m, 2 meters between 100 and 300 meters, and less than ~~2 meters per second~~ from 300 to 900 meters.

3 m/sec

2 m/sec

EXECUTIVE SUMMARY

The area covered by this study is the three dimensional tracking range west of the island of St. Croix. The range surface area is approximately 51.4 square kilometers with depths ranging from about 457 to 1280 meters.

The surface oceanography is dominated by the warm (26°C to 29°C) westerly flowing Caribbean Current and the highly persistent easterly trade winds (10 to 14 knots).

Two major water masses influence the deeper circulation. The Subtropical Underwater (SUW) extends down to about 250 meters. Below this depth the Subantarctic Intermediate Water (SAIW) extends to the bottom.

Layer depth variation ranges from 50 meters during August to 120 meters during March.

Significant wave heights of 7 feet or less occur 98 percent of the time. Sea and swell direction vary between northeast and southeast throughout the year.

Storm surges with heights in excess of one meter may occur in the southeast section of the range.

Surface air temperatures average between 24°C to 27°C during winter and between 27°C to 28°C during summer.

Visibility exceeds 18 kilometers 89 percent of the time.

ACKNOWLEDGEMENTS

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THE OCEANOGRAPHIC/METEOROLOGICAL ENVIRONMENT WEST OF ST. CROIX

PART I. INTRODUCTION

This study summarizes existing oceanographic and meteorological information on the three-dimensional underwater tracking range at St. Croix, U.S. Virgin Islands. The area of concern includes the tracking range and the surrounding waters bounded by 17°38'N-17°48'N, 65°53'W-65°00'W. (Figure 1). Meteorological data were compiled from the 1 degree Marsden Square bounded by 17°-18°N, 64°-65°W.

The tracking range, bounded by 17°42'N-17°48'N, 64°53'W-65°00'W, has a surface of about 51.4 square kilometers, with depths ranging from 457 to 1,280 meters. The oceanographic and hydrographic measurements, which provide a data base for this report, were conducted by the Naval Oceanographic Office, the Applied Physics Laboratory/University of Washington, and the Applied Physics Laboratory/Johns Hopkins University. Additional current measurements in this part of the Caribbean were made by Stalculp et al. (1972 and 1975), Sturges (1975), and Sukhovey et al. (1968). Meteorological data, in the form of synoptic summaries, were provided by the Naval Weather Service Detachment, Asheville, North Carolina, and cover the period 1859-1971.

This study is divided into three parts: environmental setting, oceanography, and climatology. Environmental setting provides the reader with a description of the general oceanography and meteorology. The remaining two parts present data that will be useful to those engaged in engineering and scientific projects at the tracking range and its surrounding waters.

PART II. ENVIRONMENTAL SETTING

The U.S. Virgin Islands are located in the Lesser Antilles chain of the West Indies. The primary water exchange route between the Caribbean Sea and the Atlantic Ocean takes place through the Jungfern Passage (Virgin Island Passage), which separates the island of St. Croix from Puerto Rico.

The Caribbean Current keeps the surface waters in the tracking range area, located west of St. Croix, at a near constant temperature that varies from a winter low of about 26°C to an autumn high of about 29°C. Surface salinity values range from a low of 34.3 parts per thousand during autumn to a high of 36.0 parts per thousand during spring (Table 1). Below the surface waters and extending down to about 250 meters, lies the Subtropical Underwater (SUW). The core of this water mass, which is located at a mean depth of 150 meters, is characterized by temperature - salinity (T-S) values that range from 23°C-37.2 parts per thousand, during winter, to 21°C-36.7 parts per thousand during autumn. Maximum depth of this water mass is at 250 meters, the depth of the 18.5°C isotherm.

Below the Subtropical Underwater (SUW) lies the Subantarctic Intermediate Water (SAIW), whose core has a near constant temperature of 6°C and a water column minimum salinity of 34.8 parts per thousand at 950 meters during all seasons.

TABLE 1. MONTHLY MEAN SEA SURFACE TEMPERATURE AND SALINITY

MONTH	TEMP (°C)	SALINITY (Parts per Thousand)
JAN	26.3	35.8
FEB	25.7	35.7
MAR	25.7	35.9
APR	26.3	35.9
MAY	26.8	36.0
JUNE	27.6	35.7
JULY	28.0	35.3
AUG	28.5	35.0
SEPT	29.0	34.6
OCT	28.8	34.3
NOV	28.2	34.4
DEC	27.2	35.0

The major meteorological influences in the area are a low pressure belt, known as the equatorial trough, and subtropical highs that are located north of the trough. The trough which migrates seasonally, has a mean latitude of 5°N, causing a net flow of air to be directed toward the equator. The resulting prevailing easterly trade winds have an annual wind-field constancy, or persistence, of 80 percent.

PART III. OCEANOGRAPHY

1. WIND-DRIVEN CIRCULATION

When wind blows over water, the wind's energy transfers to the water's surface, setting the surface into motion, and starting a surface drift current. If the wind continues to blow, the current deepens, reaching a depth that depends upon the water's stability and the wind's force. The depth at which the current is reduced to a small percent of its surface value is called the depth of frictional resistance. An estimate of the thickness of the wind-driven circulation is made using Ekman's theory. The vertical profile of the wind-driven current can either be constant or decrease, depending upon the water's stability. A shallow or steep thermocline limits the layer through which the current acts. During April through December, the underwater tracking range has an average layer depth of 60 meters. During these months, wind-driven currents are nearly constant with depth. During January through March, however, the water is mixed to a greater depth by convective processes than by the wind, and the vertical wind-driven current profile decreases linearly to a depth of about 100 meters.

Since the prevailing winds over the tracking range are from the east, the island blocks the wind, and some of the wind-induced drift current west of St. Croix is fetch-limited. The area within the triangle of Figure 1 shows the zones where wind-induced drift currents would be fetch-limited. Clockwise eddies will develop around the southern end of St. Croix, and counterclockwise eddies will develop around the northern end. The dimensions of this fetch-limited area are based upon previous work done near Barbados by James. The base of the triangle is placed perpendicular to the mean annual prevailing surface wind.

Figure 2 may be used to determine wind-induced current. Enter the figure with wind speed at the top of the graph and drop vertically to the wind duration value. Repeat this step, but use fetch distance instead of duration. Whichever step gives the lower current speed is the limiting case and the associated speed is the correct one to use.

Mean surface wind speed in the 1 degree Marsden Square surrounding the underwater tracking range during July is about 14 knots. Figure 2 shows that if a 14-knot wind blew for four hours, a steady state wind-induced surface current of 0.28 knots would result, providing the fetch was at least 10 nautical miles.

The best estimate for wind drift current direction at this latitude is 10 degrees to the right of wind direction. For an easterly wind, this direction would be toward 260 degrees.

2. NEAR-BOTTOM CIRCULATION

On 19 February 1976, the Naval Oceanographic Office implanted three current meter arrays (Table 1) to measure near-bottom flow in the range. Figures 3 through 51 present the data for all three arrays as graphical plots of frequency distributions of speeds and directions, energy spectra, and time series vector plots. Appendix A contains bivariate distribution tables of speed and direction for all three arrays.

Table 2 shows that mean current speed varied from 5.3 centimeters per second at a depth of 747 meters on Array 1, to 10.3 centimeters per second at a depth of 1,064 meters on Array 2. Mean resultant direction varied from 115 degrees at a depth of 1,018 meters on Array 2, to 322 degrees at a depth of 762 meters on Array 1.

Examination of the time series vector plots indicates that the most significant contributions to the time-dependent flow are rotary motions that have maximum amplitudes along the direction (northeast-southwest) of predominant flow at the semidiurnal tidal period of 12.42 hours.

Both clockwise and counterclockwise rotary motion occur about equally throughout the spectral record on Array 1 at 762 and 747 meters. Counterclockwise motion predominates above 0.06 cycles per hour (16.7 hours) at 1,064 meters on Array 2. Below about 0.06 cycles per hour, both clockwise and counterclockwise motions occur about equally.

At the 1,049 meter level on Array 2, the predominant rotation is counterclockwise throughout the spectral record. Both clockwise and counterclockwise motions occur about equally at the 1,018 meter level on Array 2. At all three depths, 963, 948, and 917 meters, on Array 3, the rotary motion is primarily clockwise.

The most significant feature of the spectral records is the energy peak at the semidiurnal frequency (marked with an "S" at the bottom of the graph; I and D represent the inertial and diurnal frequency)

The amplitudes of the four principal tidal constituents were determined for each of the current meter records and are tabulated in Table 3. Maximum constituent amplitude found was 6.3 centimeters per second (semi-diurnal period) at 1,064 meters on Array 2. This record also had the smallest percent of residual variance (70 percent) due to nontidal motion,

TABLE 2. CURRENT METER ARRAY STATISTICS

ARRAY[a]	LATITUDE (N)	LONGITUDE (W)	WATER DEPTH (m)	Depth (m)	MEAN CURRENT VALUES (cm/sec) Speed	East	North	Resultant	Direction (T)	Constancy[b]
1	17°43′	64°55′	777	762	6.6	−0.3	0.4	0.5	322	7.6
				747	5.3	0.3	0.5	0.6	034	11.3
2	17°45′	64°57′	1079	1064	10.3	0.9	3.1	3.2	016	31.1
				1049	7.9	1.0	0.8	1.3	052	16.4
				1018	6.4	1.6	−0.8	1.8	115	28.1
3	17°43′	64°59′	979	963	7.5	−1.1	1.9	2.2	330	29.3
				948	6.4	0.0	1.4	1.4	360	21.9
				917	6.1	0.5	0.9	1.0	026	16.4

a. All three arrays moored on 19 February 1976

b. Constancy indicates what percent of the measurement period the flow had the indicated mean current values

TABLE 3. AMPLITUDES OF PRINCIPAL TIDAL CURRENT CONSTITUENTS

ARRAY	DEPTH (M)	EAST (cm/sec) M2[a]	S2	K1	01	PERCENT RESIDUAL VARIANCE[b]	NORTH (cm/sec) M2	S2	K1	01	PERCENT RESIDUAL VARIANCE[b]
1	762	3.2	0.5	0.3	0.3	78	2.9	0.6	0.4	0.2	81
	747	1.9	0.7	0.2	0.4	85	2.6	0.9	0.3	0.4	80
2	1064	2.1	0.2	0.1	0.1	84	6.3	1.7	1.2	1.1	70
	1049	0.6	0.5	0.2	0.2	98	2.7	1.4	0.3	0.6	91
	1018	1.5	0.4	0.2	0.6	88	2.1	1.2	0.8	0.6	87
3	963	2.6	0.2	0.6	3.1	81	1.9	0.1	0.4	2.8	85
	948	2.3	0.4	0.4	2.9	82	1.9	0.4	0.2	1.4	89
	917	2.3	0.8	0.5	2.3	78	1.5	0.1	0.4	0.1	94

a. Constituent Period (Hours)

Constituent	Period (Hours)
M2	12.42
S2	12.00
K1	23.93
O1	25.82

b. Percent residual variance is the percent of total record variance due to nontidal motion

which indicates that the major portion of the record variability may be attributed to other than tidal frequency oscillations.

The amplitude of the semidiurnal constituent (M2) is larger at the deepest depth on each array. This may indicate that the tidal oscillations are affected by local bathymetry.

During October 1965, Ostericher implanted 6 current meter arrays in the tracking range. Appendix B contains Ostericher's summaries of the data. There is agreement between the October 1965 measurements at Station 8, at 1,050 meters, and the February 1976 measurements at Station 2, at 1,049 meters. The mean resulting vectors are 055 degrees at 1.5 centimeters per second for Station 8, and 052 degrees at 1.3 centimeters per second for Station 2.

In 1962, Applied Physics Laboratory, University of Washington, personnel conducted bottom current measurements near Sprat Hall. Near the beach, the flow was 10 centimeters per second toward the north. Between 0.2 and 0.6 miles offshore, the current was variable, with a maximum speed of 10 centimeters per second toward the east. At 0.8 mile off the beach, at a depth of 457 meters, the current decreased to less than 2 centimeters per second. Additional measurements from moored arrays between 11 and 18 meters above the bottom indicate variable current speeds averaging between 5 to 15 centimeters per second.

3. INTERMEDIATE CIRCULATION

During October 1965, Ostericher implanted 6 arrays in the range. He found a southerly flow at 760 meters (Subantarctic Intermediate Water) that moved at a mean speed of 3 centimeters per second. Appendix B contains Ostericher's summaries.

During November 1974 through January 1976, the Applied Physics Laboratory of Johns Hopkins University made a series of current-structure measurements throughout the range, with spatial separations from 100 meters to 2 kilometers. Current structure was determined by acoustically tracking slowly sinking, untethered floats, which stopped at a predetermined depth and then returned to the surface.

Results of the measurements indicate that the currents are vaiable in speed and direction. The speeds ranged from 0 to 30 centimeters per second and averaged 15 centimeters per second, with no predominant direction. The root mean square value of the vertical gradient of current (shear) at any depth is proportional to the average density gradient at that depth. Maximum current shear of 1.2 centimeters per second per meter toward 043 degrees occurred at a depth of 100 meters. Appendix C contains plots of the vertical current profiles obtained.

4. SURFACE CIRCULATION

During October and November 1962, the University of Washington's Applied Physics Laboratory used surface drogues weighted and tethered, 3 meters below the surface at 17°43'N, 64°54'W. Flow was southerly, between 10 and 20 centimeters per second.

For 2 days in October 1965, Garrison used weighted drogues to measure the range's surface currents. He planted 5 drogues in a north-south line 64°58'W and between

17°41'N and 17°47'N. On the first day, the wind was southeast at 6 knots, and the drogues moved northwest at 20 centimeters per second. During the second day, the wind speed increased and the drogue's speed increased to 24 centimeters per second.

During 17 and 18 March 1964, Garrison released two untethered floats which were acoustically tracked. Float 1 (dropped at 17°43.8'N, 64°55.5'W) recorded a maximum current of 12 centimeters per second at 267 meters. Float 2 (dropped at 17°43.2'N, 64°55.4'W) recorded a maximum current of 10 centimeters per second at 6.0 meters.

5. LAYER DEPTH VARIATION

There are two types of processes that tend to mix the water and create layer depths: (1) wind or turbulent mixing, and (2) convective mixing. Convective mixing occurs as a result of changes in the stability of the water column, which may be produced by surface cooling or by an increase in salinity. In this region, small changes in surface conditions can initiate convective processes. James (1966) showed that a temperature decrease of 0.01°C, or an increase in salinity of 0.01 parts per thousand are sufficient to start the process. Changes in layer depth due to wind mixing occur through the turbulent action of the wind. Within the tracking range, the mean-monthly layer depth varies from a maximum of about 50 meters during August to a maximum of about 120 meters during March (Figure 52). The mean layer depth during January through March is about 100 meters, and about 60 meters during the remainder of the year. These variations appear to be the result of convective mixing rather than wind turbulence, since during the period of maximum-mean wind speed, June through August, the layer depth is at a minimum. In addition, the monthly mean wind speeds are not strong enough to produce layer depths in excess of about 25 meters. Examination of the seasonal variation in temperature and salinity shows that there is a significant change in the thermohaline structure between October and February which causes deeper mixing during the winter months. The convective process is stronger in waters where the vertical temperature and salinity gradients are not steep. The salinity gradient during February is about one-half the salinity gradient during October (1.04 parts per thousand/100 meters, 2.54 parts per thousand/100 meters), and the temperature gradient is approximately eight times stronger during October than February (4.6°C/100 meters, 0.6°/100 meters). Such differences in the temperature-salinity gradients can account for the monthly variations in the layer depths due to changes in the stability of the water column.

6. TEMPERATURE, SALINITY, AND SOUND VELOCITY

Typical mean values for temperature, salinity, and sound velocity during February and October are shown in Figures 53 through 55. Maximum variations in these parameters occur in the first 100 meters of depth. Maximum differences between sound velocity profiles amount to about 3 meters per second in the first 100 meters, about 2 meters per second between 100 and 300 meters, and less than 2 meters per second from 300 to 900 meters. Similar variations occur between temperature and salinity curves.

Between 100 and 200 meters, the core, or maximum value of the Subtropical Underwater appears. It is at this depth (150 meters) that major semidiurnal (12.4 hours) oscillations occur. Semidiurnal amplitudes of about 0.5°C have been reported. Similar semidiurnal oscillations of salinity, with amplitudes of about 0.35 parts per thousand, have also been reported by Ridley (1963) and Garrison (1966).

At about 950 meters, a minimum salinity occurs at the core of the Subantarctic Intermediate Water. Similar semidiurnal oscillations should be expected at this depth. Figure 56 shows the T-S (temperature-salinity) correlation curves for February and October.

Typical short period variations in temperature at selected depths during February and August are shownin Figures 57 and 58. The time series, although short, indicate, that the oscillations in temperature are in phase at each depth.

7. SEA AND SWELL

The monthly averages of significant wave heights (the average height of the highest one-third waves present) vary with the wind magnitude throughout the year. July, the month having the highest average wind speed (14.0 knots), also has the monthly high in significant wave heights greater than 6 feet (Figure 59).

Significant wave heights are 4 feet or less 71 percent of the year, and 7 feet or less 98 percent of the year.

Both sea (waves produced by local winds) and swell (waves from distant storms) are consistently out of the east during all months (Figures 60 and 61). On an annual mean basis, 93 percent of the time, waves are from the northeast to southeast; 77 percent of the time, swell is northeast to southeast. These estimates are for areas in the tracking range not affected by the leeward sheltering of the island.

Generally, both sea and swell are present in an area. Figure 62 shows that the average wave heights tend to cluster around 10- to 11-second periods.

8. EXTREME WAVES

An observed wave height of 32 feet or more, with easterly winds of 55 knots, was reported just southeast of Mona Island during the passage of tropical storm Gerda in September 1958. The storm, passing to the south of the area on a westerly course, dissipated south of Cuba without ever reaching hurricane strength.

As there are insufficient data for a climatological conclusion on extreme wave heights, the values tabulated below (from reference 5) contain a statistical estimate of maximum wave occurrences.

Mean Recurrence Interval	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
Maximum Wave Height (feet)	33	37	44	49	55

From this table, it can be expected that every 10 years there may be one occurrence where wave height attains 37 feet (11 meters) in the deeper waters of the underwater tracking range.

PART IV. CLIMATOLOGY

1. PRESSURE

The surface barometric pressure pattern over the underwater tracking range is influenced by the North Atlantic (Bermuda) High throughout the year, while the annual migration of the equatorial trough imparts a seasonal influence.

The seasonal change in sea-level pressure is not large. The average monthly values range from an October-November low of 1013 millibars to a winter high of 1016 millibars. The winter maximum is a product of the seasonal migration of the equatorial trough southward and the penetration into the area of an occasional continental anticyclone. The mean annual pressure for the area is about 1015 millibars. Diurnal pressure variations are about as large (3 millibars) as the seasonal variations.

Lowest pressures are likely to occur during the tropical storm season, May through November. A pressure of 996 millibars was recorded near Mona Passage, west of the tracking range, during the passage of hurricane Beulah in September 1967.

2. WINDS

Variations in the average monthly wind speeds are small, ranging from 10.4 knots in October to 14.0 knots in July, with an annual mean of 12.1 knots. A secondary maximum occurs during the winter, when continental fronts and associated northers penetrate the area. Winds of tropical storm force (intensity greater than 33 knots) have been observed for all months. Mean monthly wind speeds and directions are shown in Figures 63 through 65.

Factors which interrupt the trade wind flow are frontal and easterly wave passages. As the cold front approaches, the wind shifts to a southerly direction, the front passes, there is a gradual shift through the southwest and northwest quadrants back to the east. The easterly wave passage is characterized by an east-northeast wind ahead of the wave and a change to east-southeast following its passage.

3. EXTREME WINDS

Although the number of marine observations for wind are approximately 40,000 for the period 1856-1971, the fact that ships avoid bad weather introduces a fair-weather bias into extreme wind statistics. The return values of maximum sustained winds shown below are statistical estimates.

Mean Recurrence Interval	5 Yr	10 Yr	20 Yr	50 Yr	100 Yr
Maximum Sustained Wind (knots)	70	75	83	91	99

These estimates suggest that there will be a maximum sustained wind speed of 75 knots in the area once every 10 years.

4. TROPICAL CYCLONES

The trade wind flow is interrupted by tropical cyclones, an important feature of the range's climate during the summer and early autumn. Because of seasonal shifts in areas of tropical cyclone development, the range is outside the main paths of the most severe tropical atmospheric disturbances, except from July through October.

Of the approximately 600 tropical cyclones recorded over the North Atlantic since 1886, 52 penetrated the area bounded by 17.5° - 20.0°N and 64.0° - 70.0°W; of these 22 were hurricanes, 26 were tropical storms, and the remaining four were tropical depressions. August and September had the majority with 14 and 24 storms, respectively. Based on an 84-year record, the probability of at least one tropical storm or hurricane penetrating the area in any given year is 0.44.

Those hurricanes and tropical storms which do severely affect the area develop primarily over the waters of the southern North Atlantic to the east of the Lesser Antilles. The movements of the storms are usually toward the west and northwest at an average speed of 10 to 15 knots.

5. STORM SURGES

Storm surges may affect parts of the range area, particularly the southeastern section which contains the shallowest depths. There are three components of the storm surge. The first is due to the onshore component of wind stress which moves water toward the coast; the second component is due to the deflection of the current in the longshore direction. The third component produces a change in sea level due to reduced atmospheric pressure in the vicinity of storms and hurricanes. Along the coast toward which the hurricane is advancing, the water may begin to rise when the storm center is still 740 to 926 kilometers away. Over the open ocean storm surges may be in excess of 1 meter. Heights several times this value occur at coastal areas near St. Croix.

6. VISIBILITY

Visibility is good throughout this area; 89 percent of the time it exceeds 18 kilometers. Sea or vapor haze, the result of salt particles being thrown up by heavy seas can reduce visibility to less than 10 kilometers. Sea fog rarely occurs, except occasionally near the coast.

7. TEMPERATURE

Surface air temperatures average between 24°C to 27°C during winter months and 27°C to 28°C during summer. Temperatures above 32°C occur during summer and autumn. The temperature of the sea-surface averages from 0.5°C to 1.5°C warmer than that of the overlying atmosphere for all months, with winter and summer having the greatest and least differences. Such small differences in temperatures between the air and sea reflect the dominating influence of the sea on the marine atmosphere. The mean monthly sea surface temperature is highest during August and September (29°C), and lowest during February and March (26°C).

8. PRECIPITATION

Mean monthly precipitation is evenly distributed throughout the year. A relatively dry season occurs during winter and early spring. A relatively wet season occurs from May through November.

There are two rainfall-producing mechanisms in the area: easterly waves and cold fronts. During the rainy season, the area experiences easterly atmospheric waves. An intense easterly wave brings one or more cloudy, rainy days which may produce sufficient rain to cause flooding on the island.

Occasionally, the trailing edge of a cold front off North America penetrates the area and brings a change in the weather that ranges from cloudier-than-normal skies to heavy and continual rainfall lasting for several days.

Most of the precipitation that falls over the area lasts less than 1 hour.

9. CLOUDS

Cloud cover does not vary greatly from season to season. The seasonal variation of cloudiness shows a maximum (obscured) during September (11 percent cloud cover). Average monthly cloud cover increases slightly from a minimum of about 29 percent in May to a maximum of about 37 percent in August. The annual norm is 32 percent. In all seasons, maximum cloudiness and precipitation occur during the afternoon and night. Total obscuration of the sky, although infrequent, occurs primarily during short-duration rain showers. Figure 66 shows the monthly variation of cloud cover.

Most of the cloudiness consists of trade-wind cumulus. This type of cumulus is generally of small vertical extent, with the bases averaging 610 to 914 meters in height. Cloud tops average 1,829 to 2,438 meters in winter, and increase in summer, rising from 2,743 to 3,962 meters over the higher elevations of St. Croix. Other clouds, such as the cumulonimbus and stratiform types, occur during the passage of easterly atmospheric waves, frontal systems and tropical storms.

10. RELATIVE HUMIDITY

The relative humidity is high, averaging 78 percent over the course of the year. The monthly average percentages range from a February low of 71 percent to a May high of 82 percent. The average annual diurnal variation is between 74 and 80 percent.

PART V. REFERENCES

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PART VI. ANNOTATED BIBLIOGRAPHY

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Preliminary analysis of 36 current meter records from 18 arrays in the eastern Caribbean Sea showed wide variation in mean speed ranging from less than 1 cm/sec near St. Croix and Viques to a maximum of about 90 cm/sec between St. Lucia and St. Vincent at a depth of 45 meters. Ten of the records had significant tidal current signatures with maximum amplitude of the M2 constituent attaining approximately 24 cm/sec at 590 meters between St. Lucia and St. Vincent. Data were recorded during all four seasons as depths ranging from 45 meters to 1910 meters. Data are presented in form of histograms, frequency distributions, progressive vector plots, power spectra, and harmonic analysis.

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Oceanographic Station data were collected in the tracking range during October and November 1962. Nansen casts, cores, and BT's were taken. A time series plot of salinity in depth is shown. Data are presented in the standard NODC format.

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The geostrophic method is applied to six north-south hydrographic profiles across the Caribbean Sea to determine the circulation field. Wind influence, baroclinic field of mass, and upwelling are considered. An estimate of the vertical velocities are given using the equations of motions.

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Oceanographic Station data taken aboard the R/V ATLANTIS during 1933-1934 are used to describe the various water masses throughout the Caribbean Sea and its many passages. The horizontal and vertical distribution are discussed as well as the general and bottom circulation.

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Time series oceanographic data off the west coast of St. Croix were examined for variations in physical properties which significantly affect sound propagation. Changes of the order of 3 m/sec occurred over a 12-hour period. Sediment cores and the textural and chemical characteristics are discussed.

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Current meters were placed at 100, 450, 800, and near the bottom at three locations (17°34'N, 65°30'W; 17°01'N, 63°43'W; and 15°40'N, 63°48'W) during April and May 1974. Moderate speeds up to 39 cm/sec were recorded at the 450m depth at 14°49'N, 63°48'W. Speeds generally were low and decreased with depth. Eighty-eight percent of all recorded speeds were less than 19 cm/sec. Data are presented in the form of histographs, frequency distribution and time-varying vector plots.

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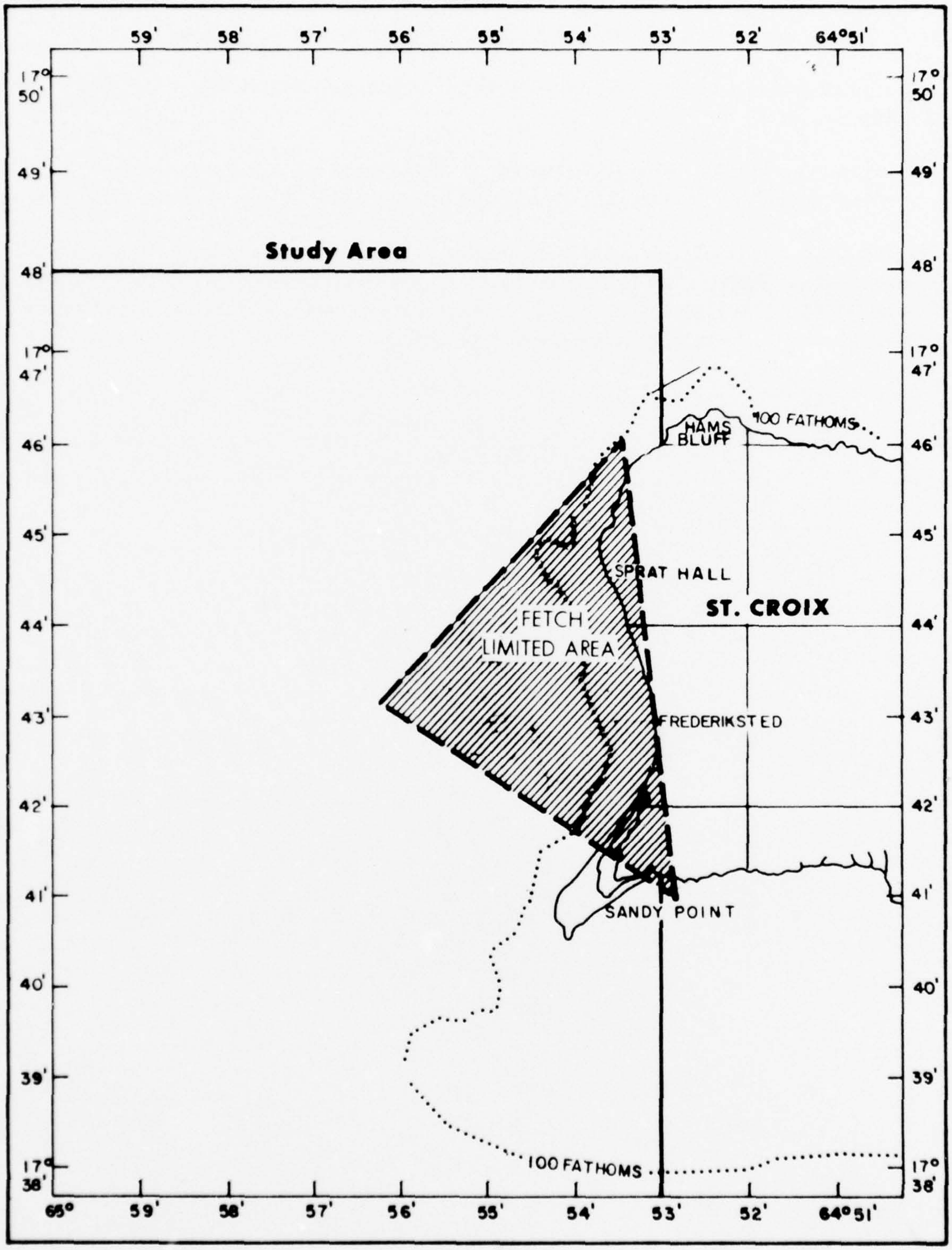


FIGURE 1 STUDY AREA

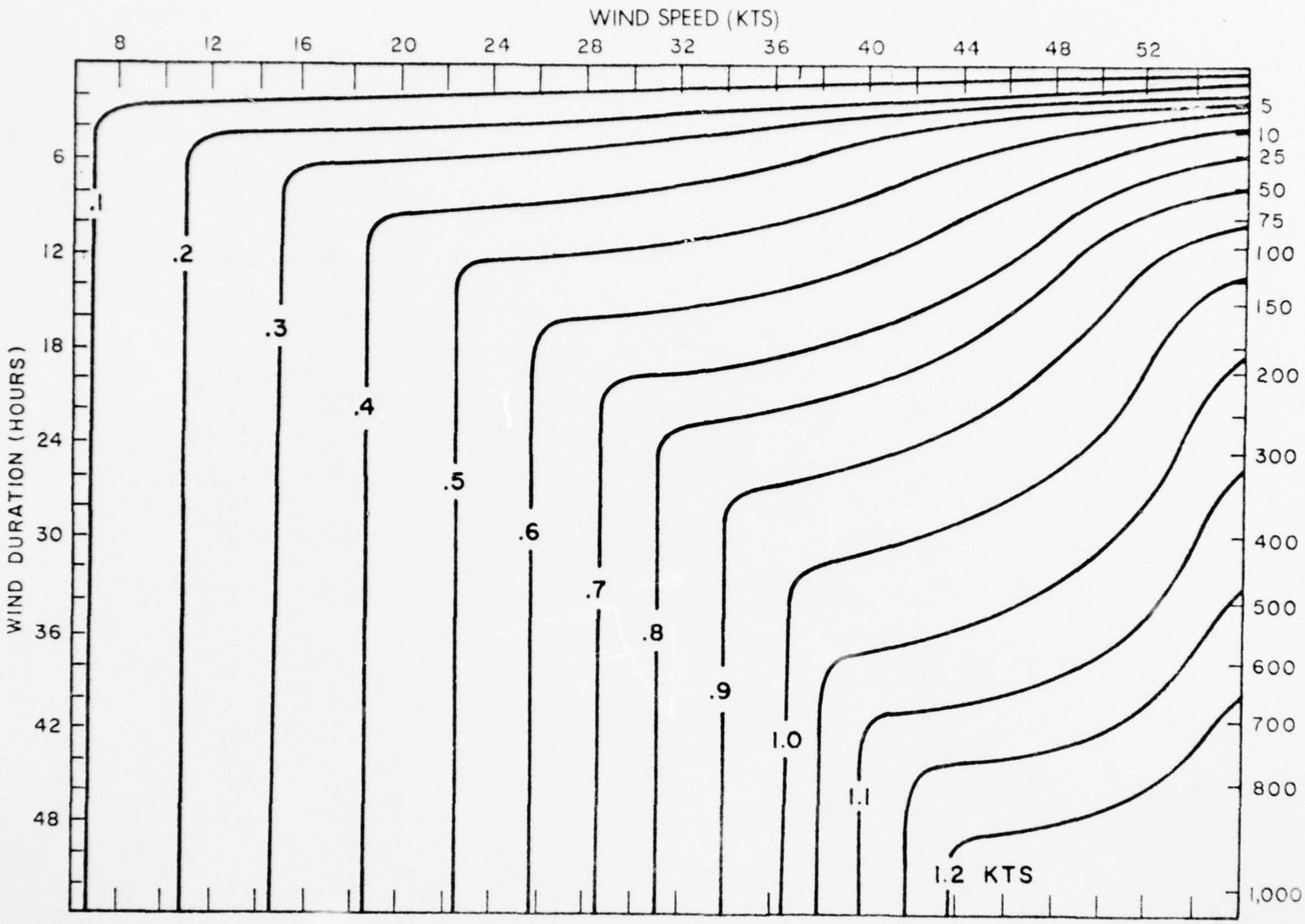


FIGURE 2 WIND DRIFT CURRENT SPEED VS WIND SPEED, FETCH, AND DURATION

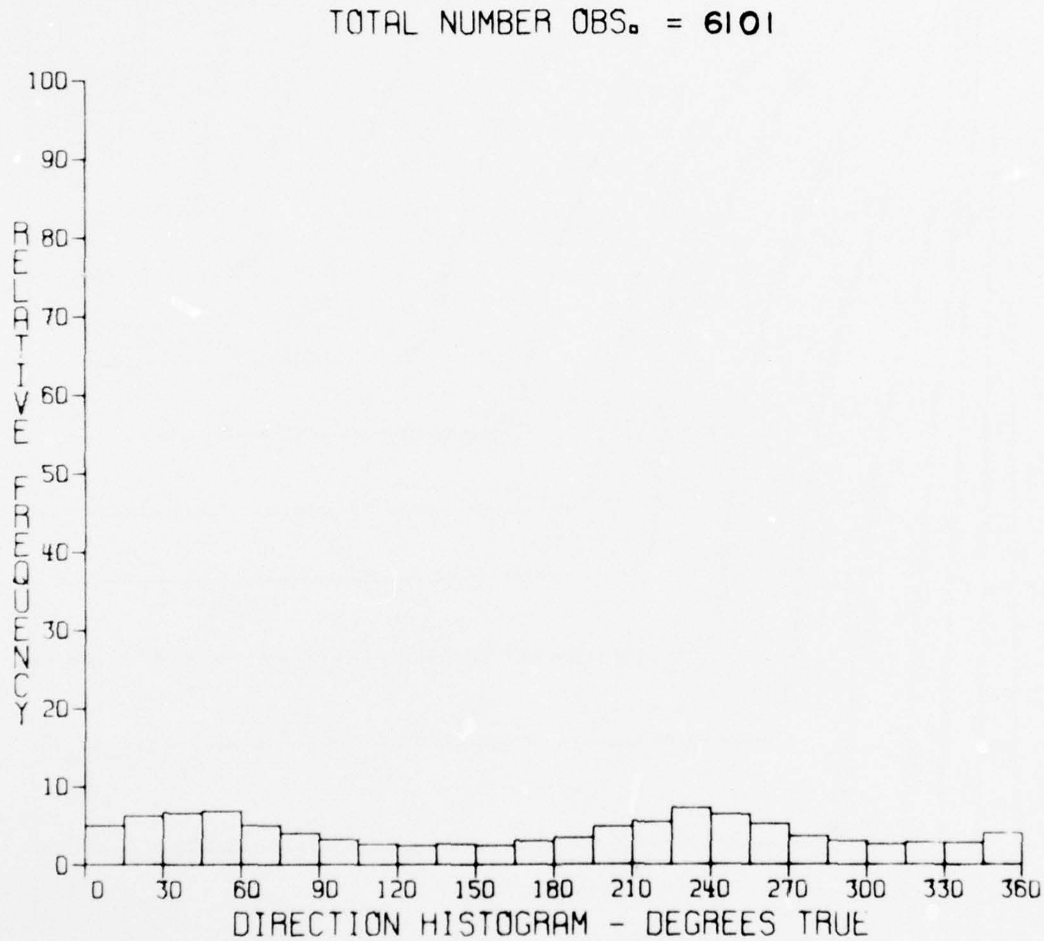


FIGURE 3 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION
FOR ARRAY 1 AT 762 METERS

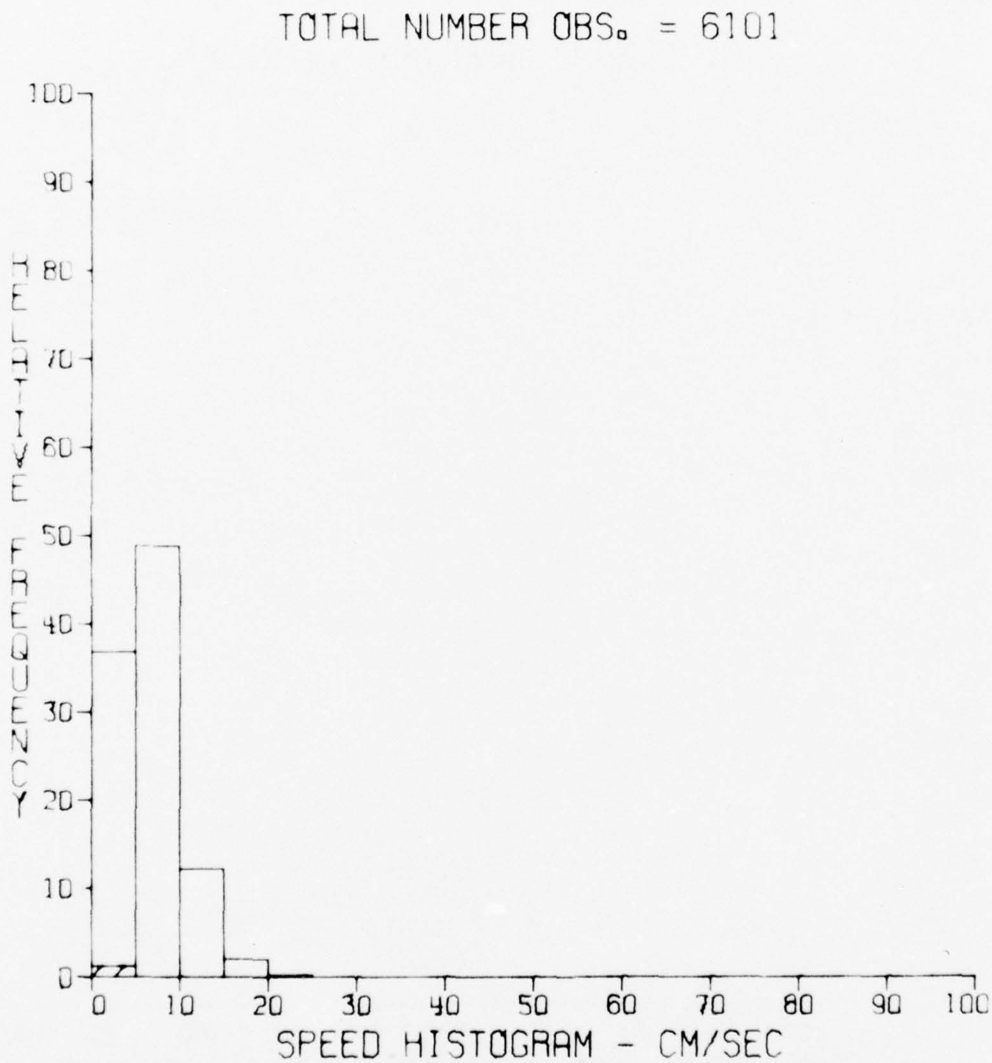


FIGURE 4 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 1 AT 762 METERS

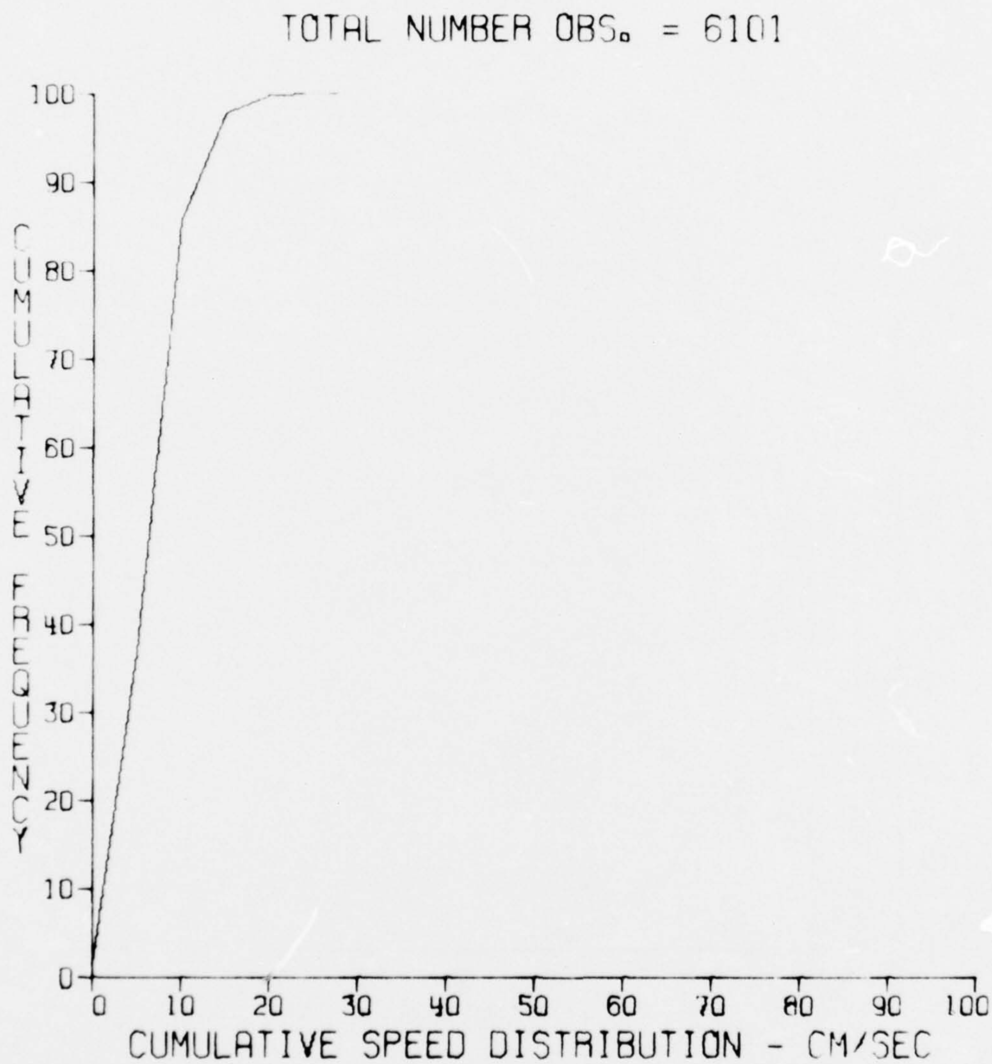


FIGURE 5 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 1
AT 762 METERS

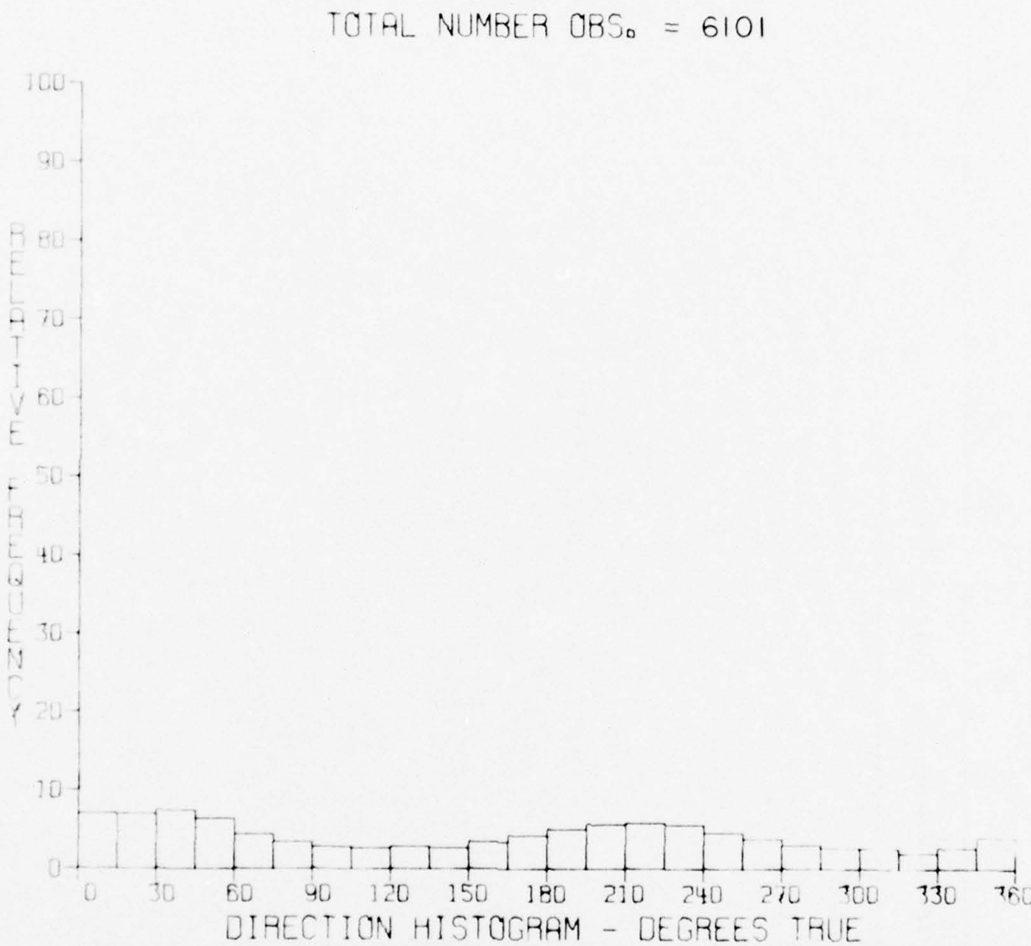


FIGURE 6 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 1 AT 747 METERS

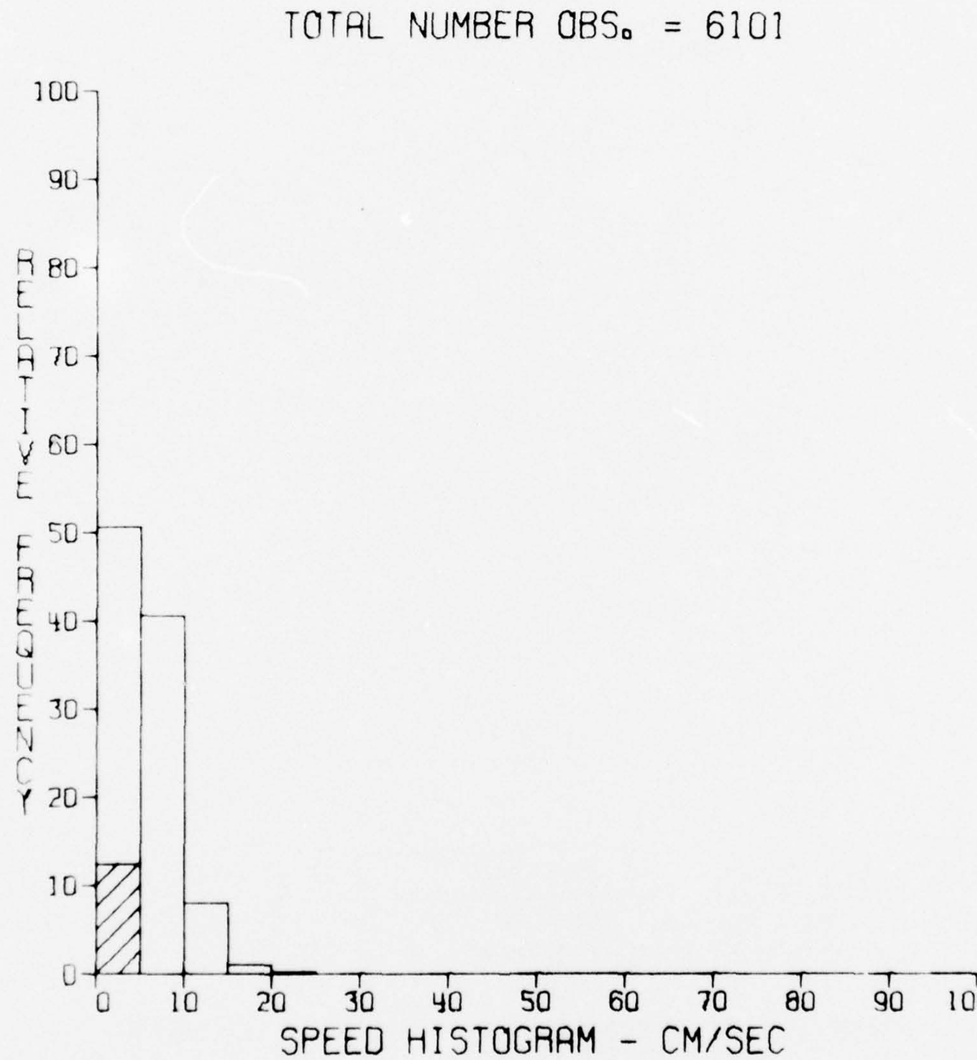


FIGURE 7 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 1 AT 747 METERS

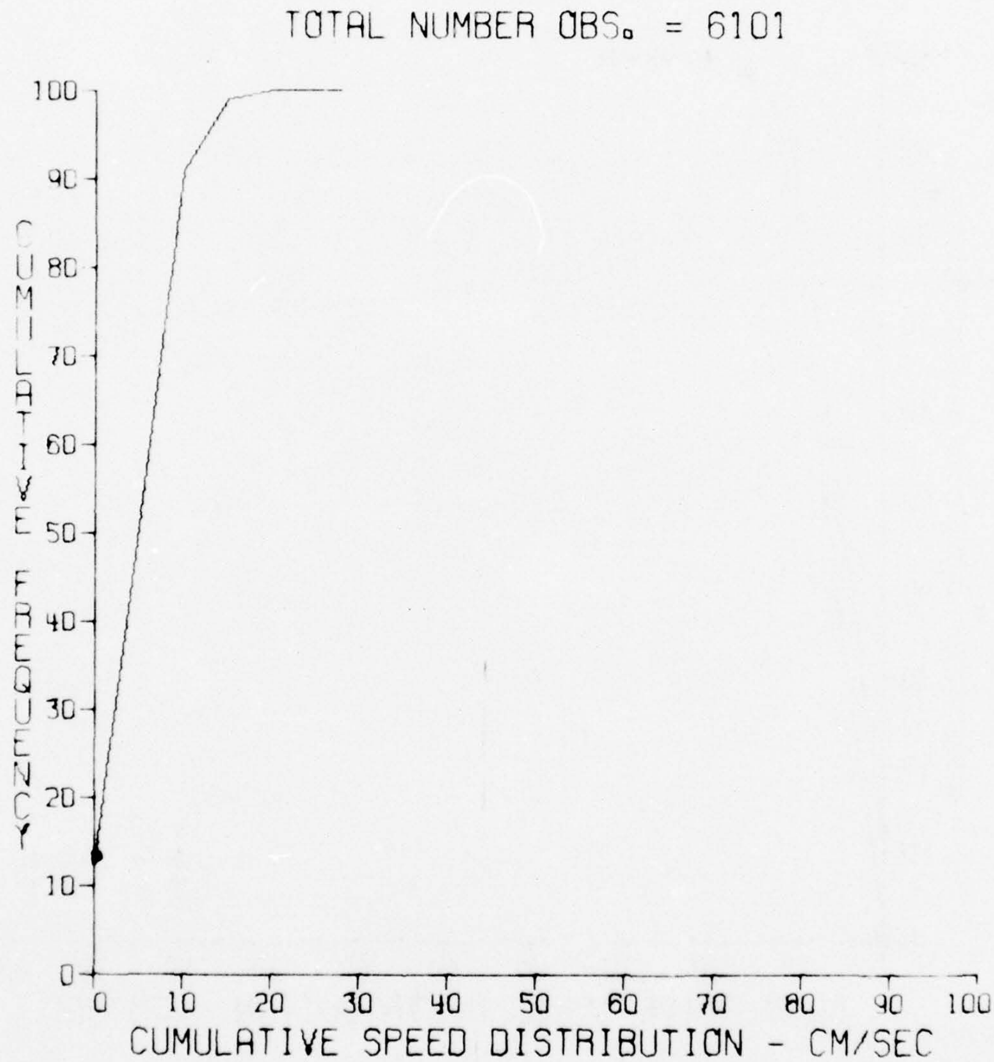


FIGURE 8 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 1 AT 747 METERS

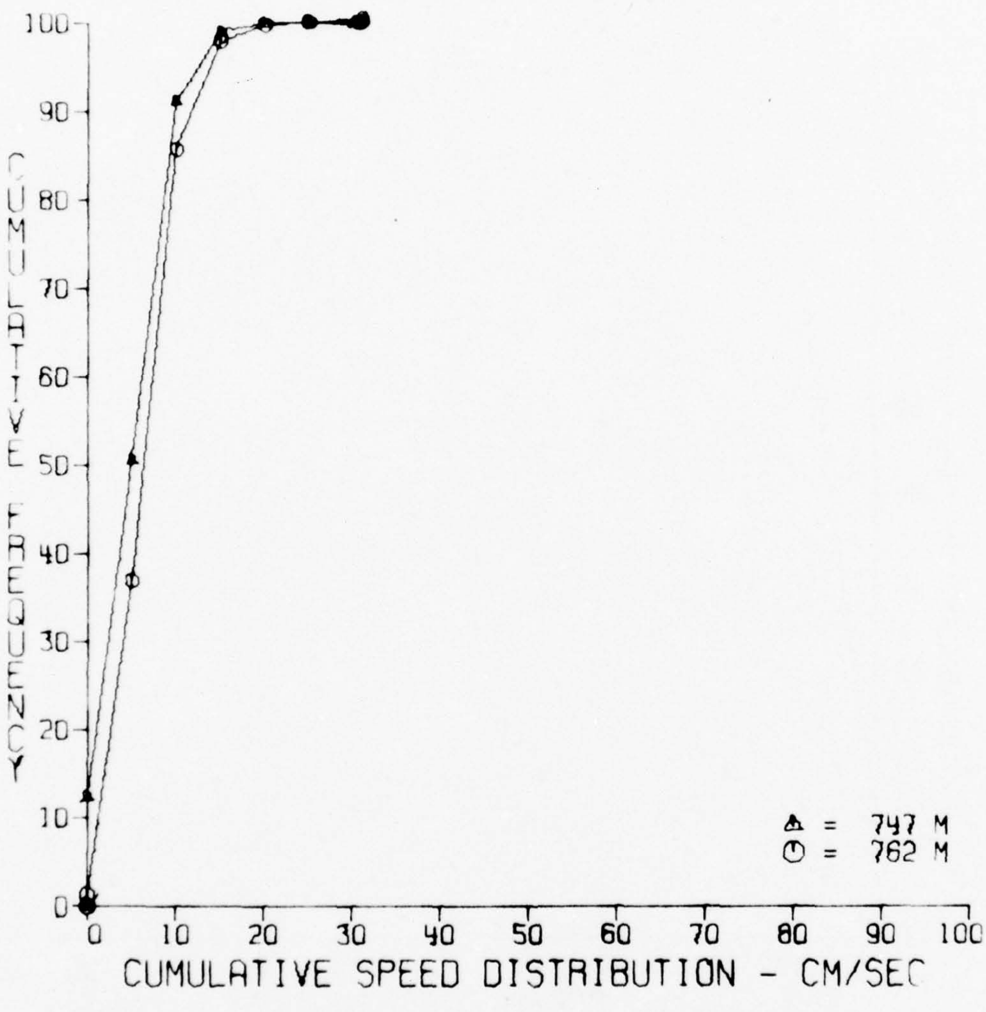


FIGURE 9 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 1 AT 762 AND 747 METERS

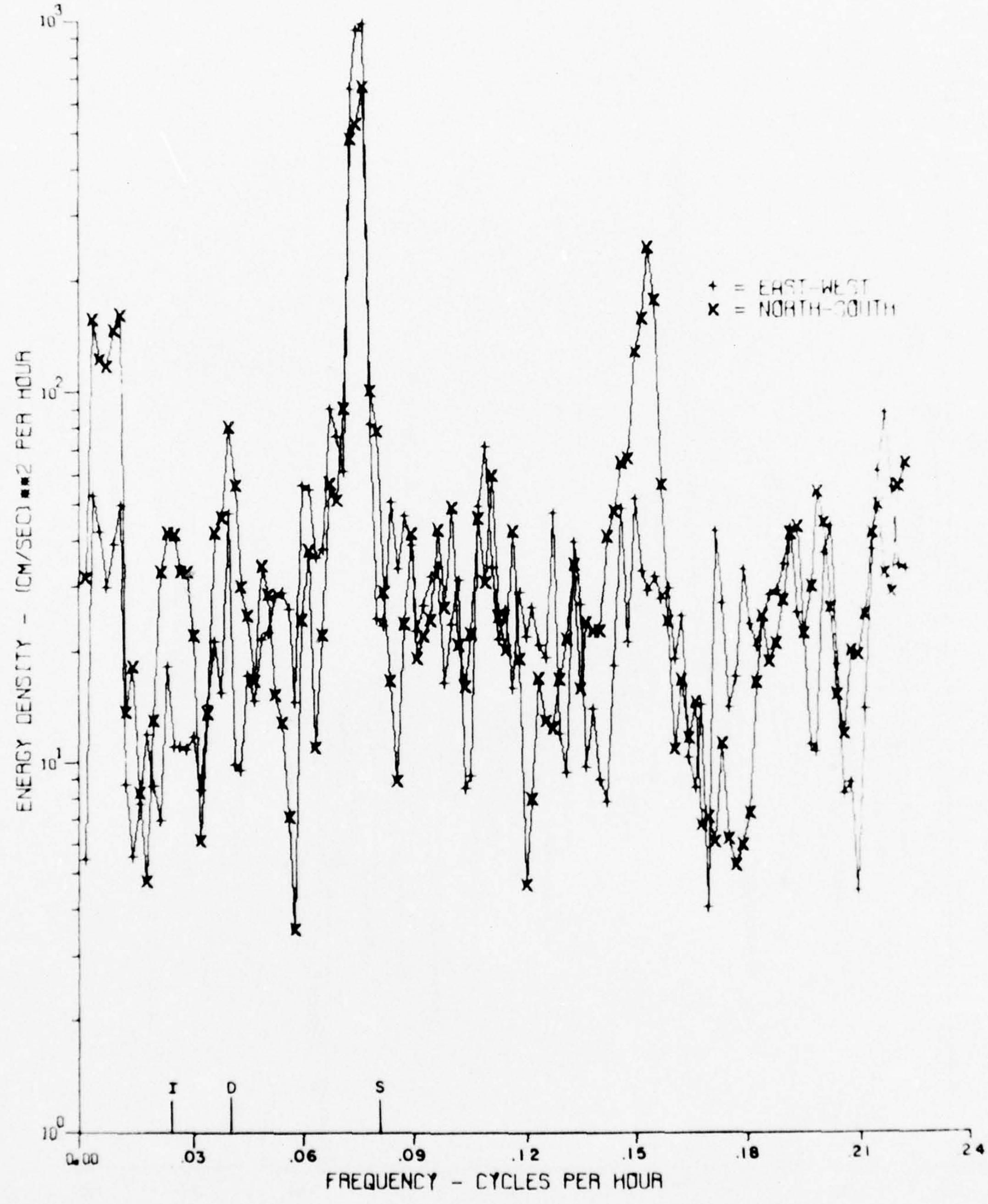


FIGURE 10 COMPONENT ENERGY SPECTRA FOR ARRAY 1 AT 762 METERS

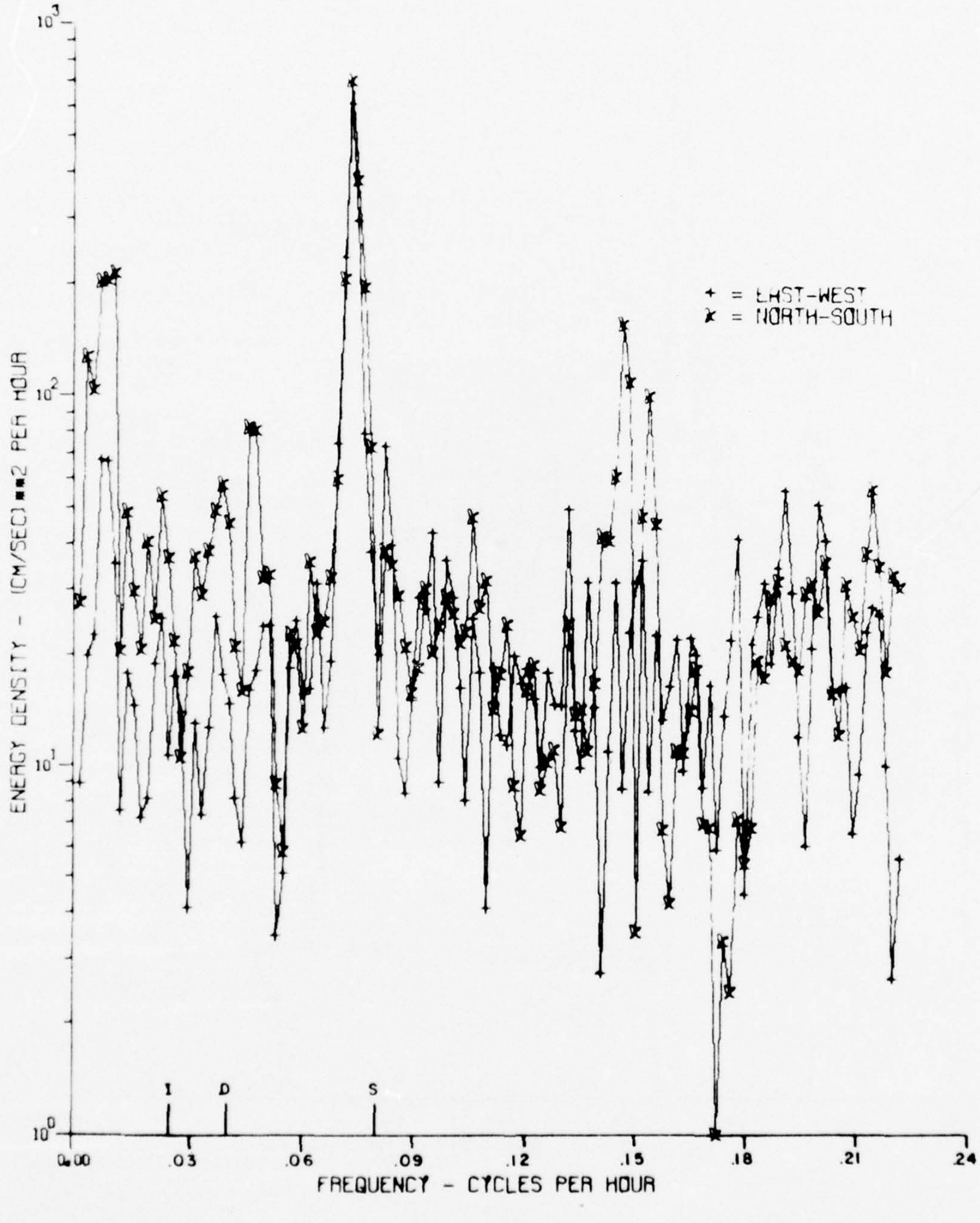


FIGURE 11 COMPONENT ENERGY SPECTRA FOR ARRAY 1 AT 747 METERS

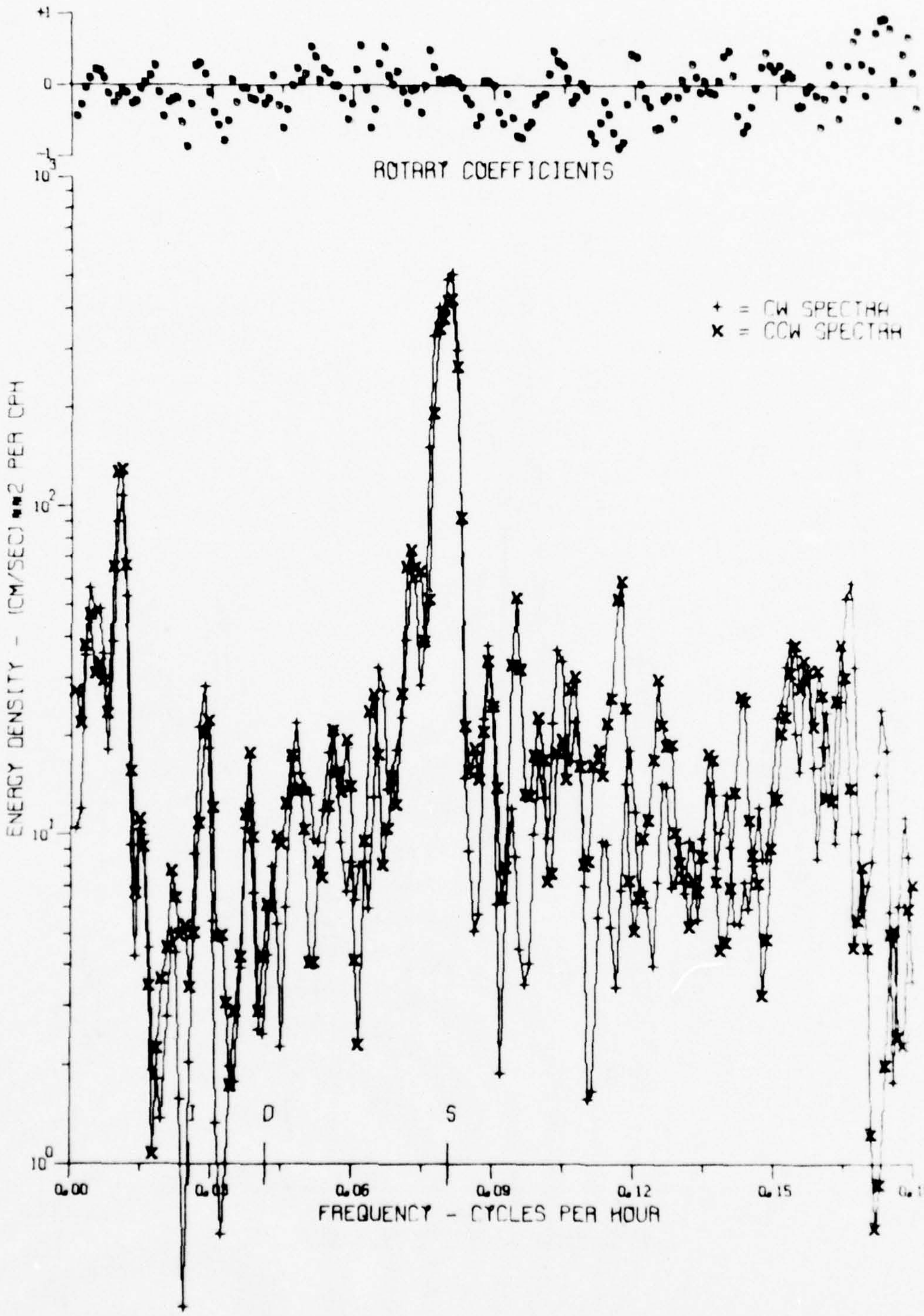


FIGURE 12 ROTARY ENERGY SPECTRA FOR ARRAY 1 AT 762 METERS

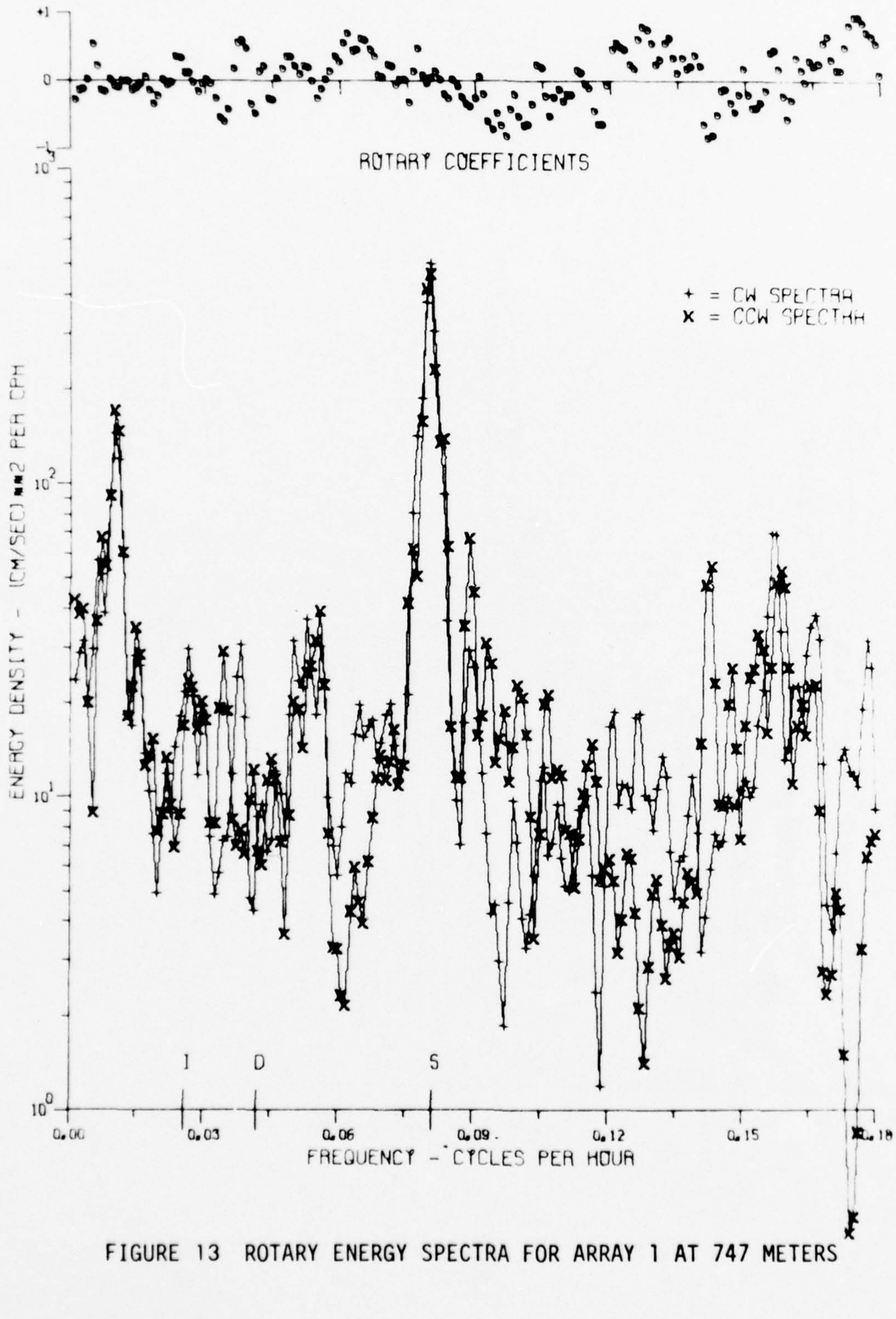


FIGURE 13 ROTARY ENERGY SPECTRA FOR ARRAY 1 AT 747 METERS

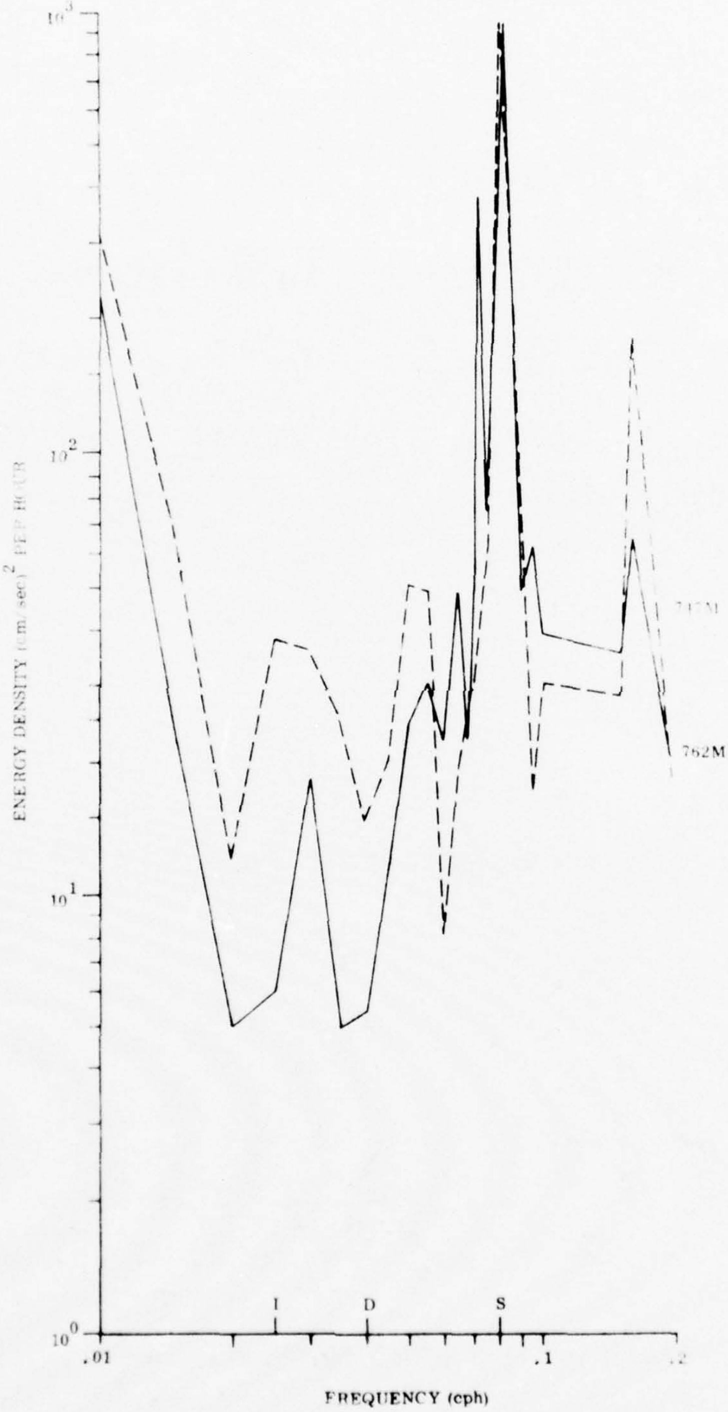


FIGURE 14 TOTAL ENERGY SPECTRA FOR ARRAY I AT 762 AND 747 METERS

ST CROIX VI ARRAY 1 FEB 1976

START TIME 0000Z 25 FEB 1976

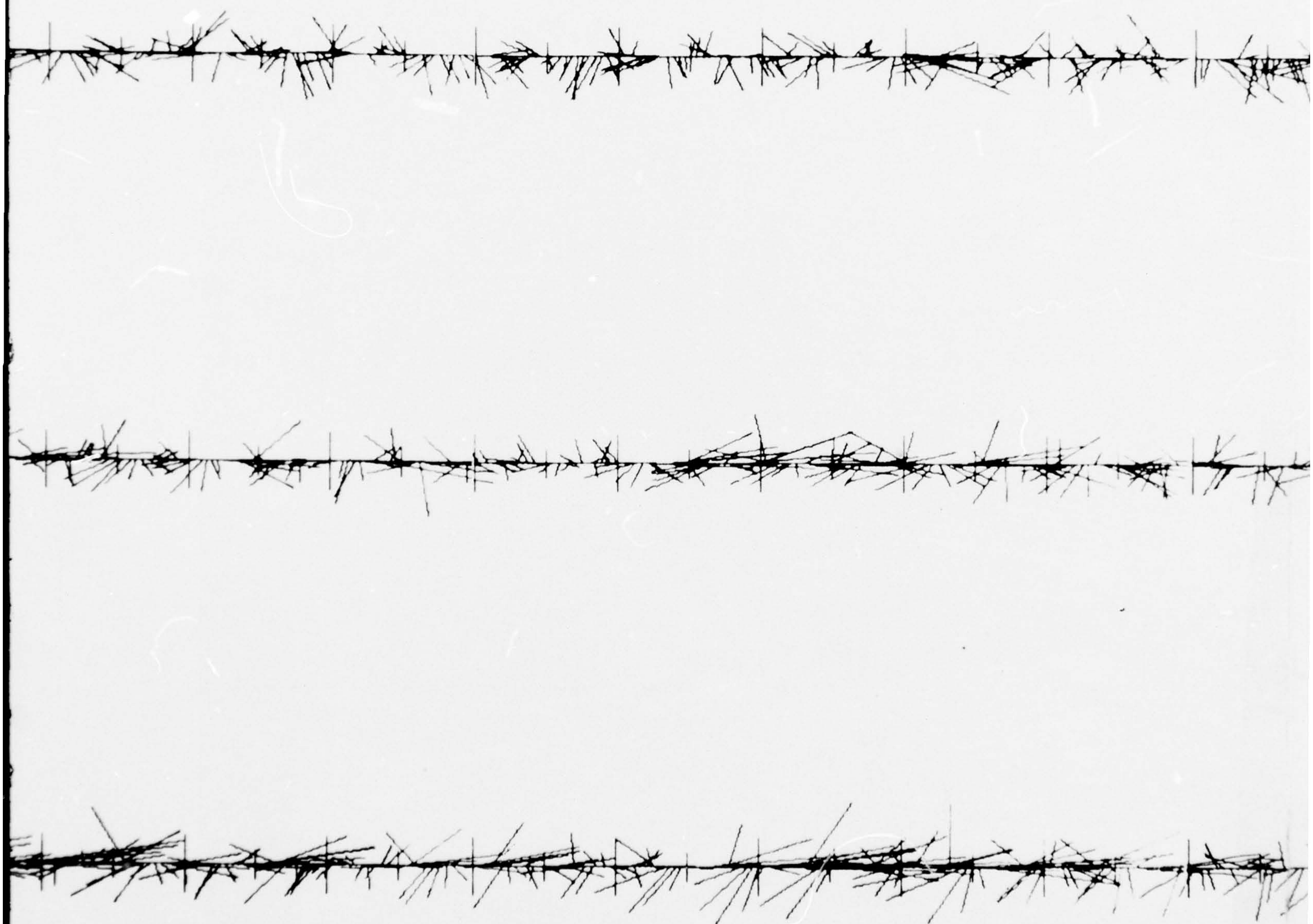
ONE HOUR AVERAGES

CURRENT METER	DEPTH - METERS
VACM-264	762
VACM-291	747

SCALE = 10 CM/SEC PER CM 0 5 10 15 20 25 30 35 40 45 50

FIGURE 15 TIME SERIES VECTOR PLOT, ARRAY 1


START TIME 0000Z 23 FEB 1976
DEPTH
(METERS)
1064
12
HOURS
1049
1018



4

5

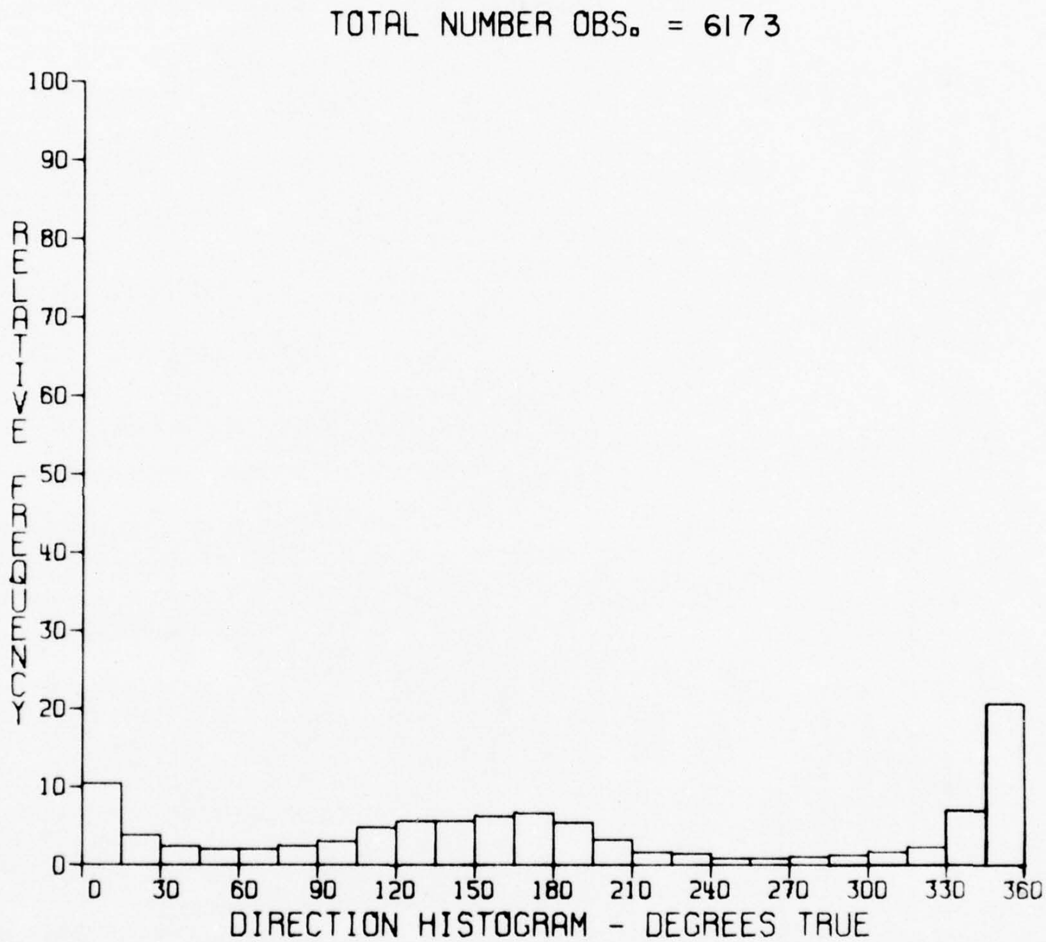


FIGURE 16 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 1 AT 1064 METERS

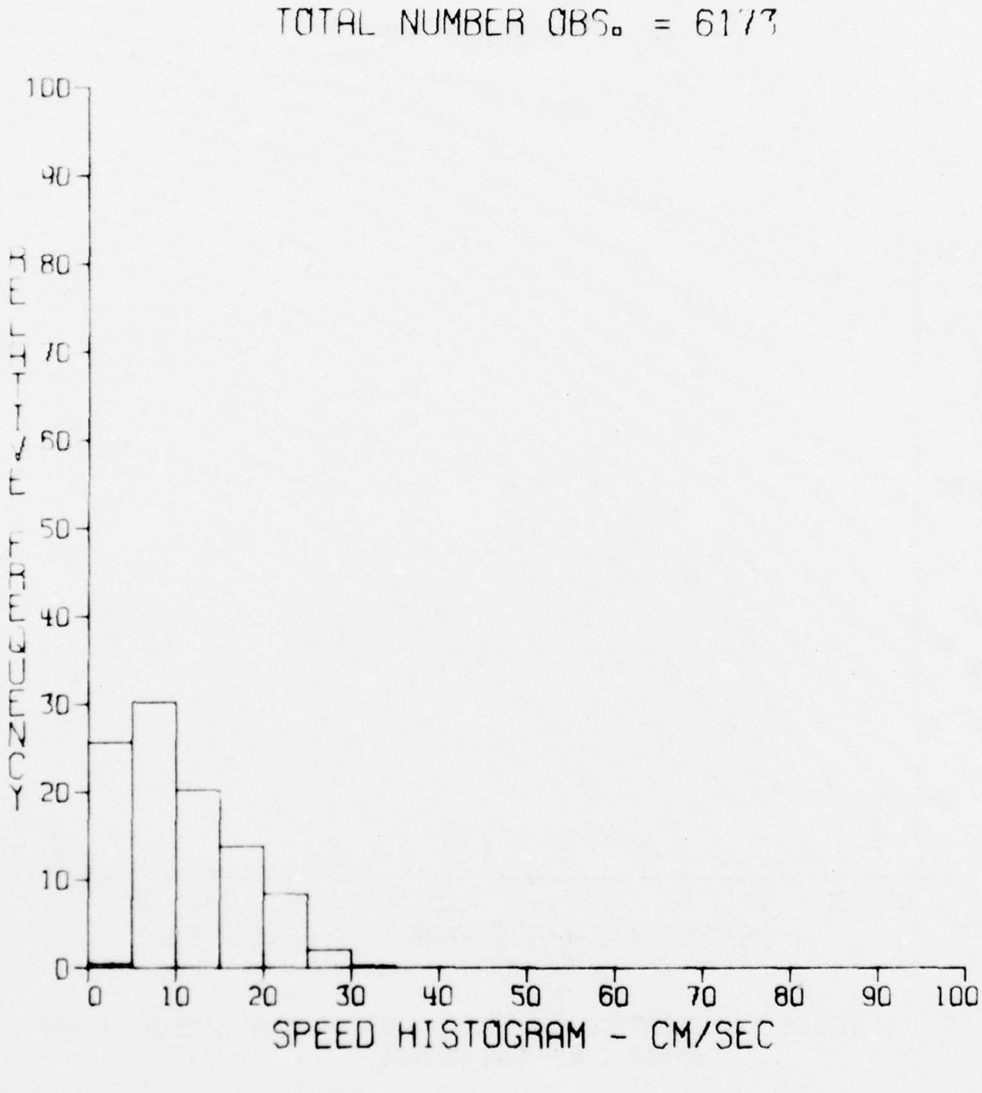


FIGURE 17 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY I AT 1064 METERS

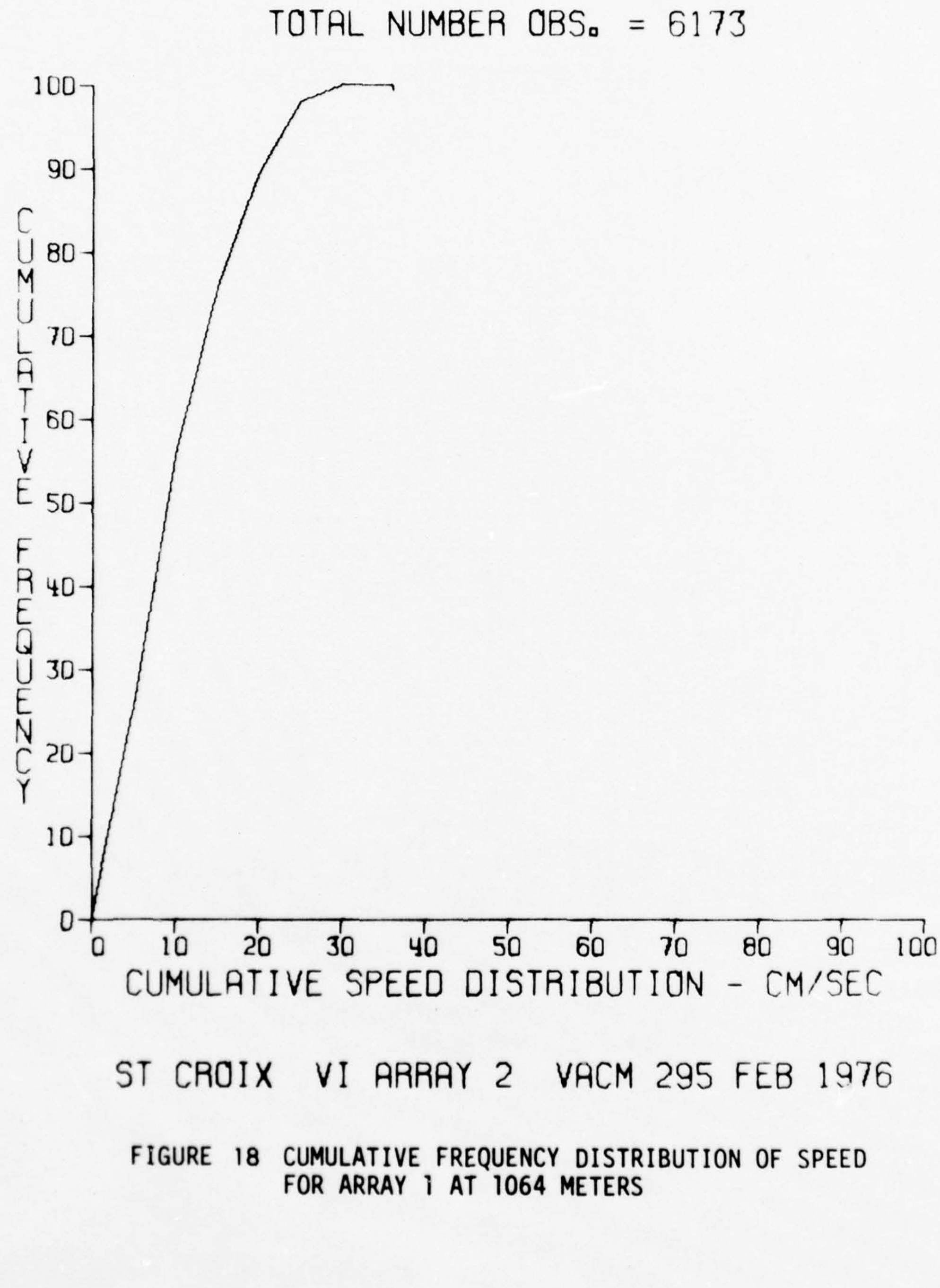


FIGURE 18 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 1 AT 1064 METERS

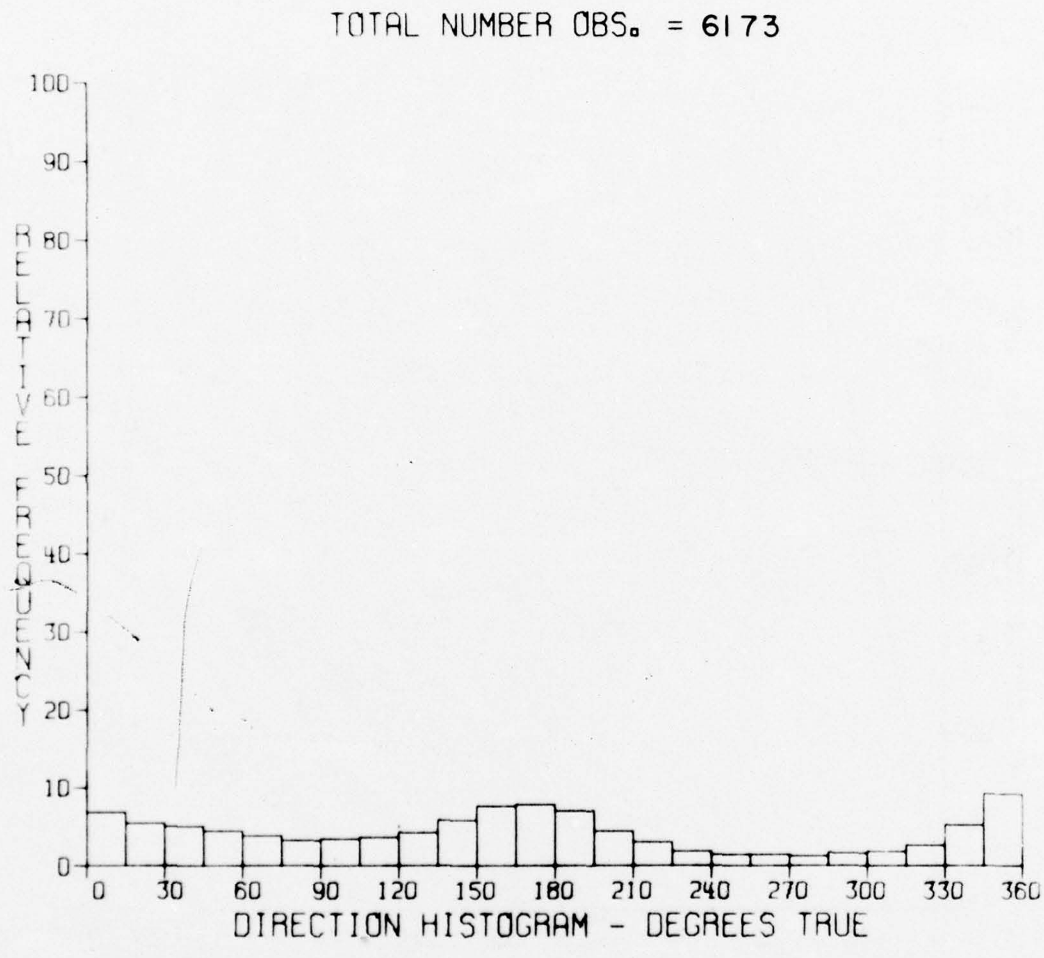


FIGURE 19 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 2 AT 1049 METERS

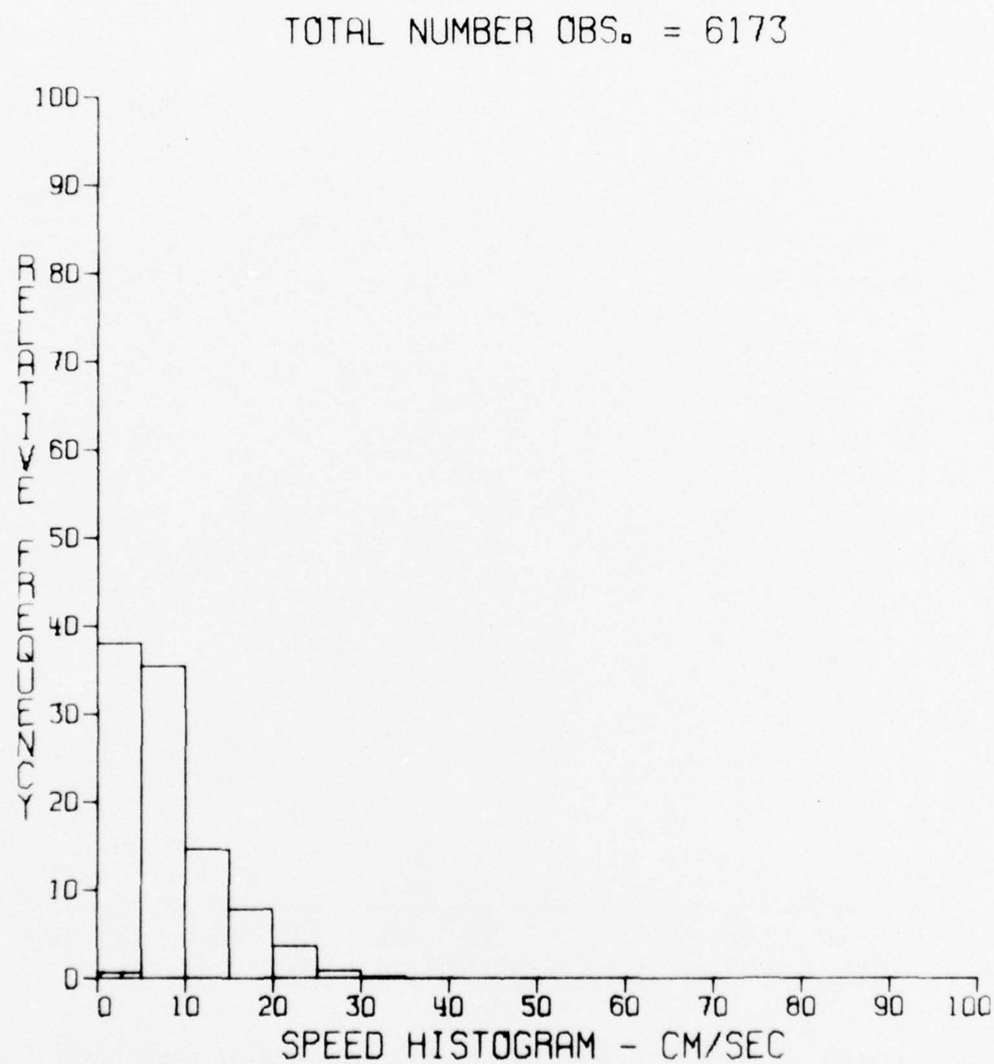


FIGURE 20 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 2 AT 1049 METERS

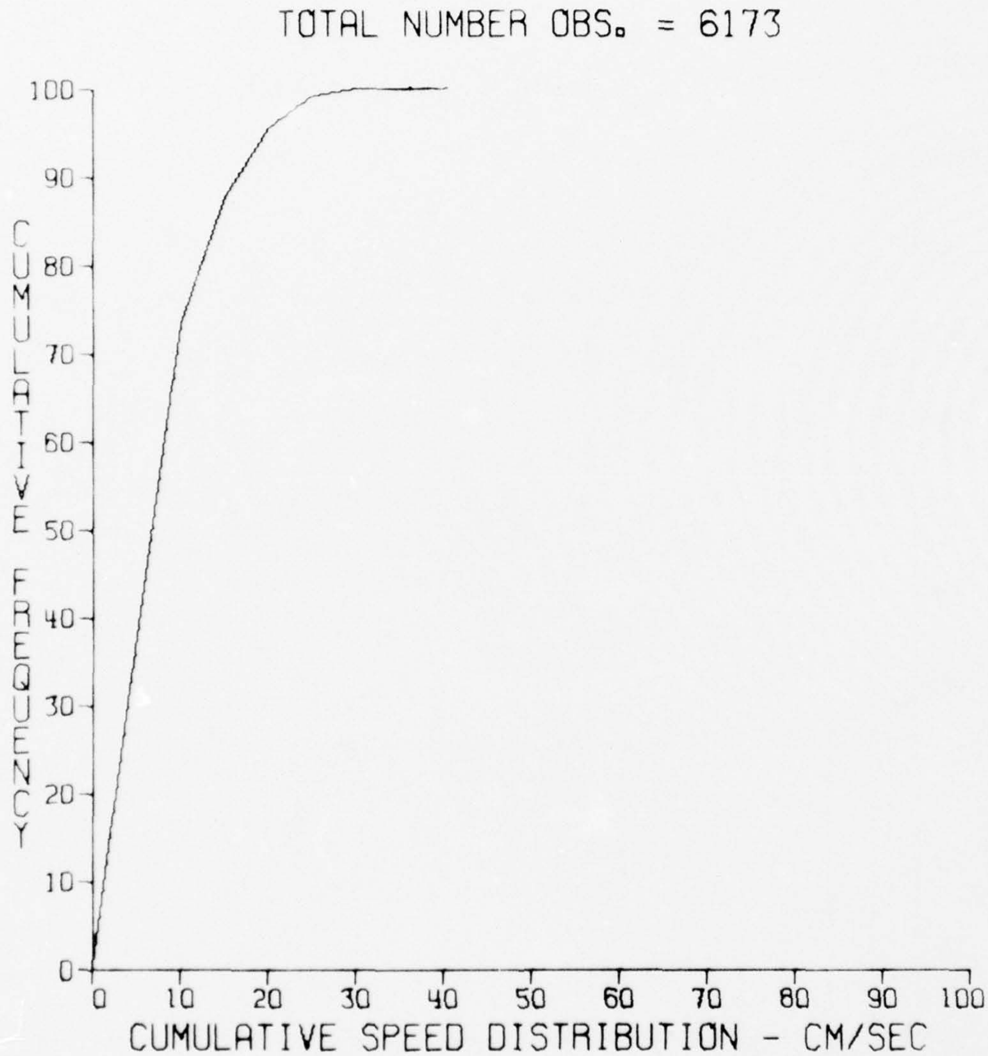


FIGURE 21 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 2 AT 1049 METERS

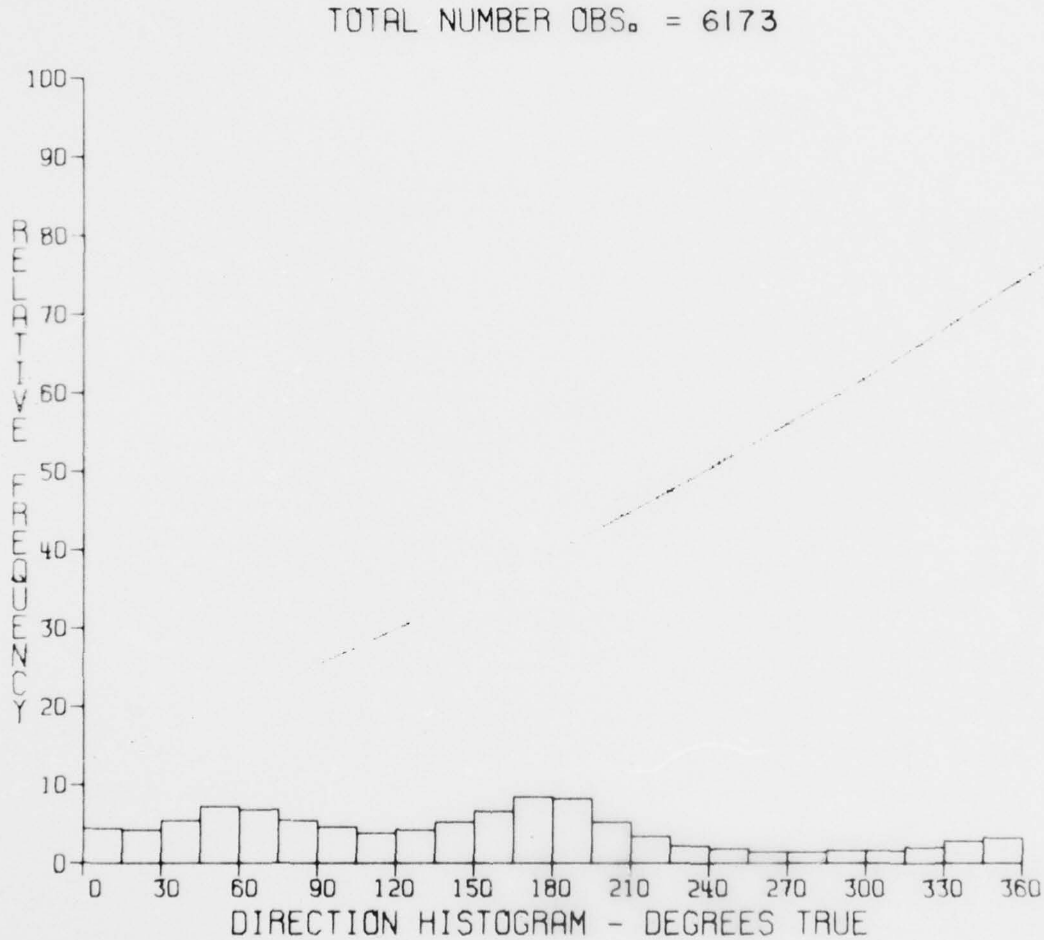


FIGURE 22 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 2 AT 1018 METERS

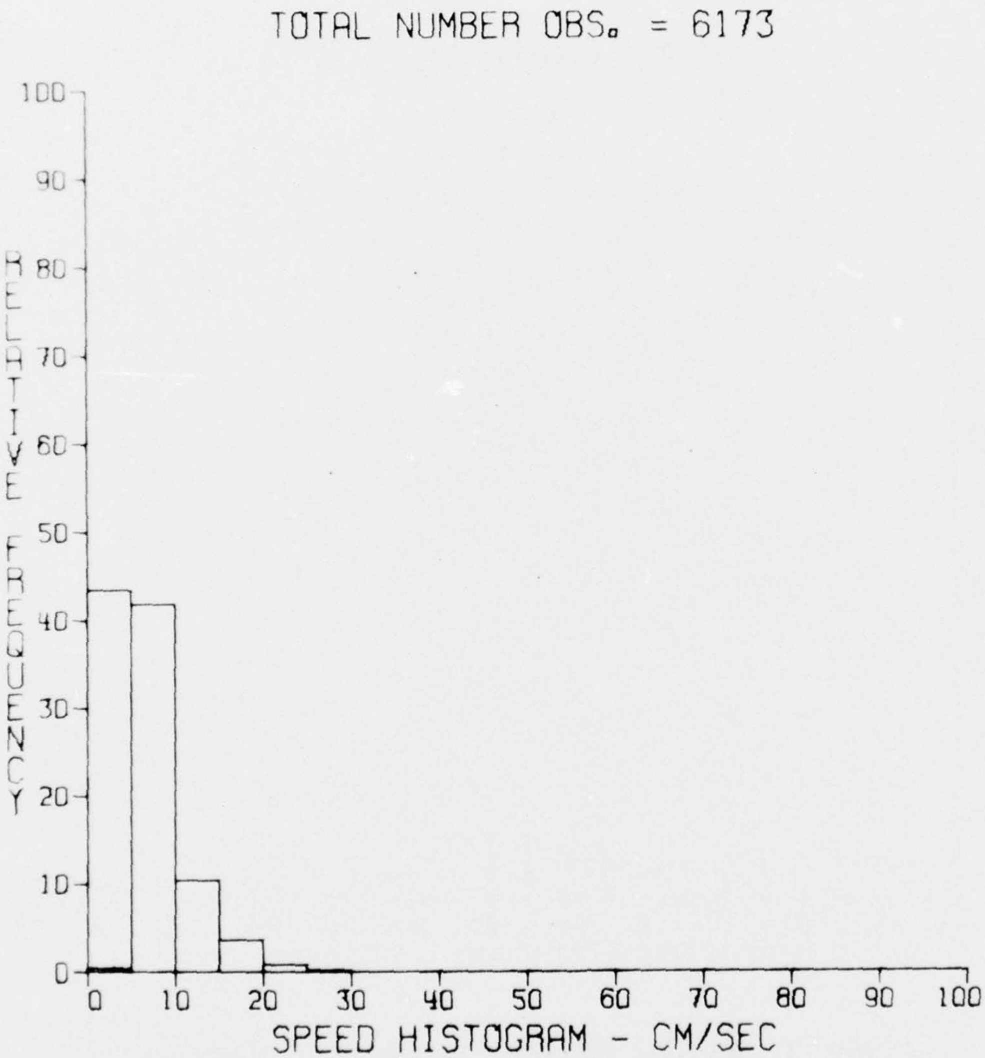


FIGURE 23 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 2 AT 1018 METERS

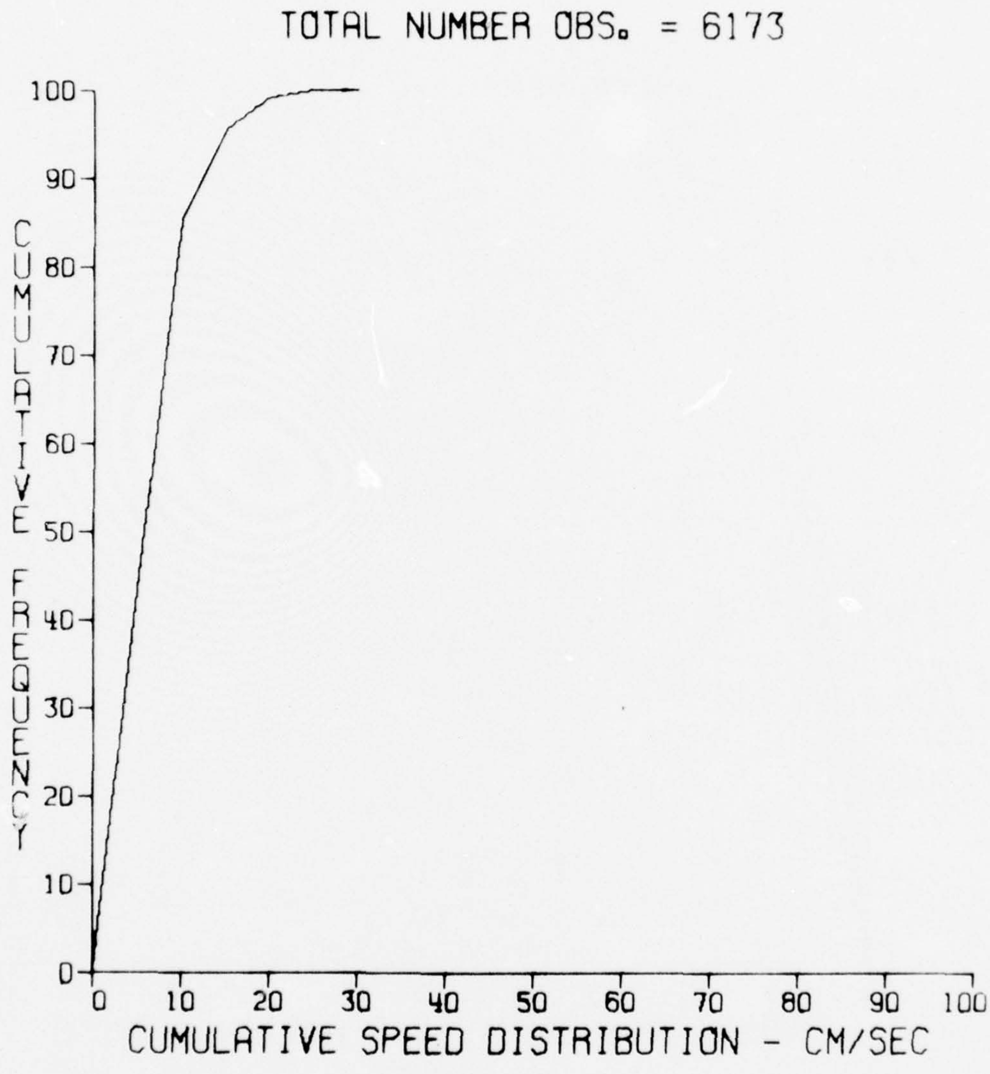


FIGURE 24 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 2 AT 1018 METERS

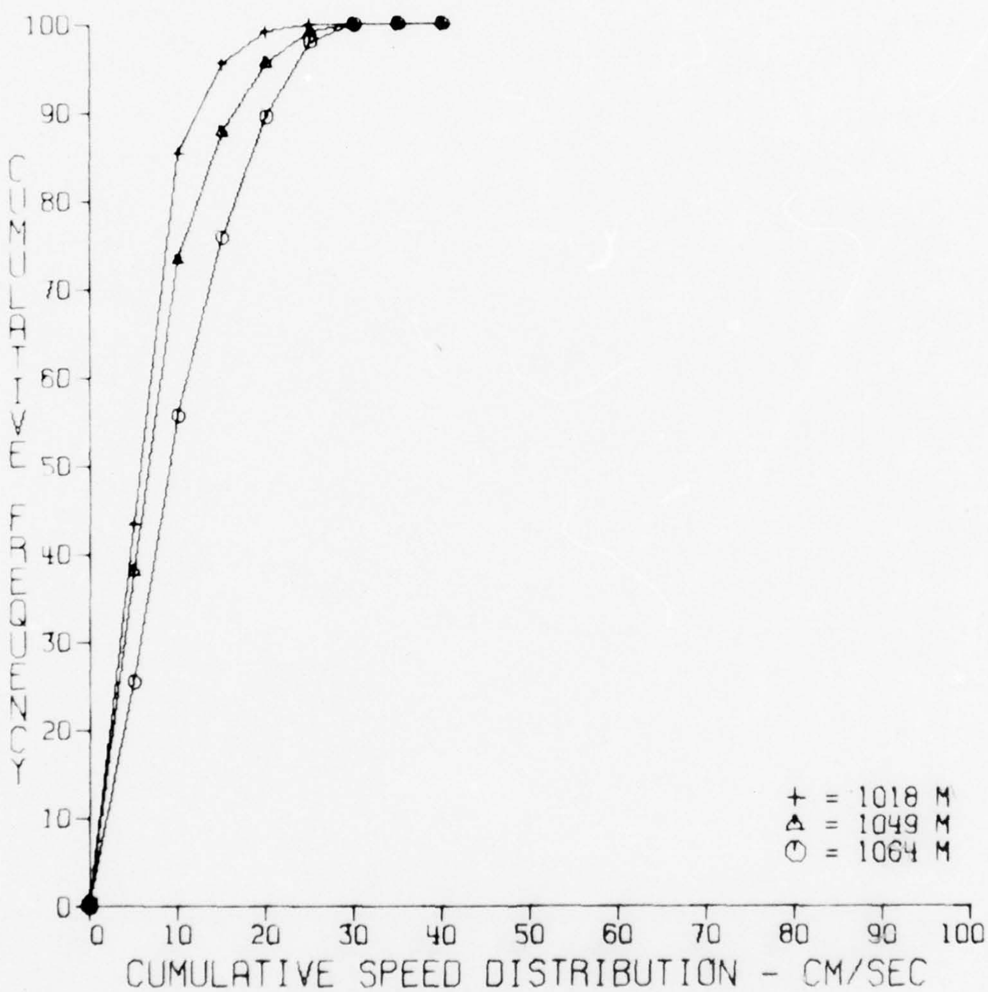


FIGURE 25 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 2 AT 1064, 1049, AND 1018 METERS

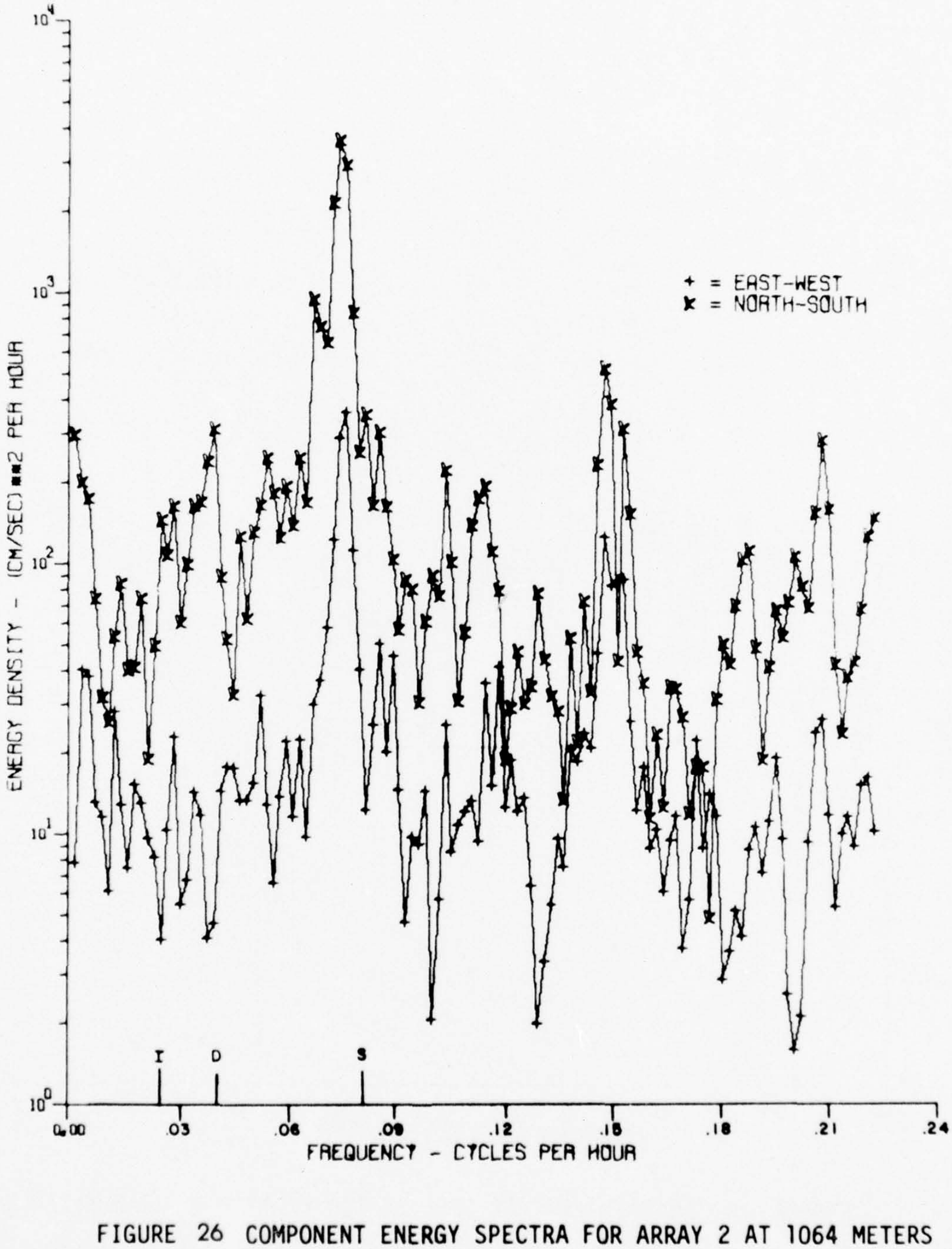


FIGURE 26 COMPONENT ENERGY SPECTRA FOR ARRAY 2 AT 1064 METERS

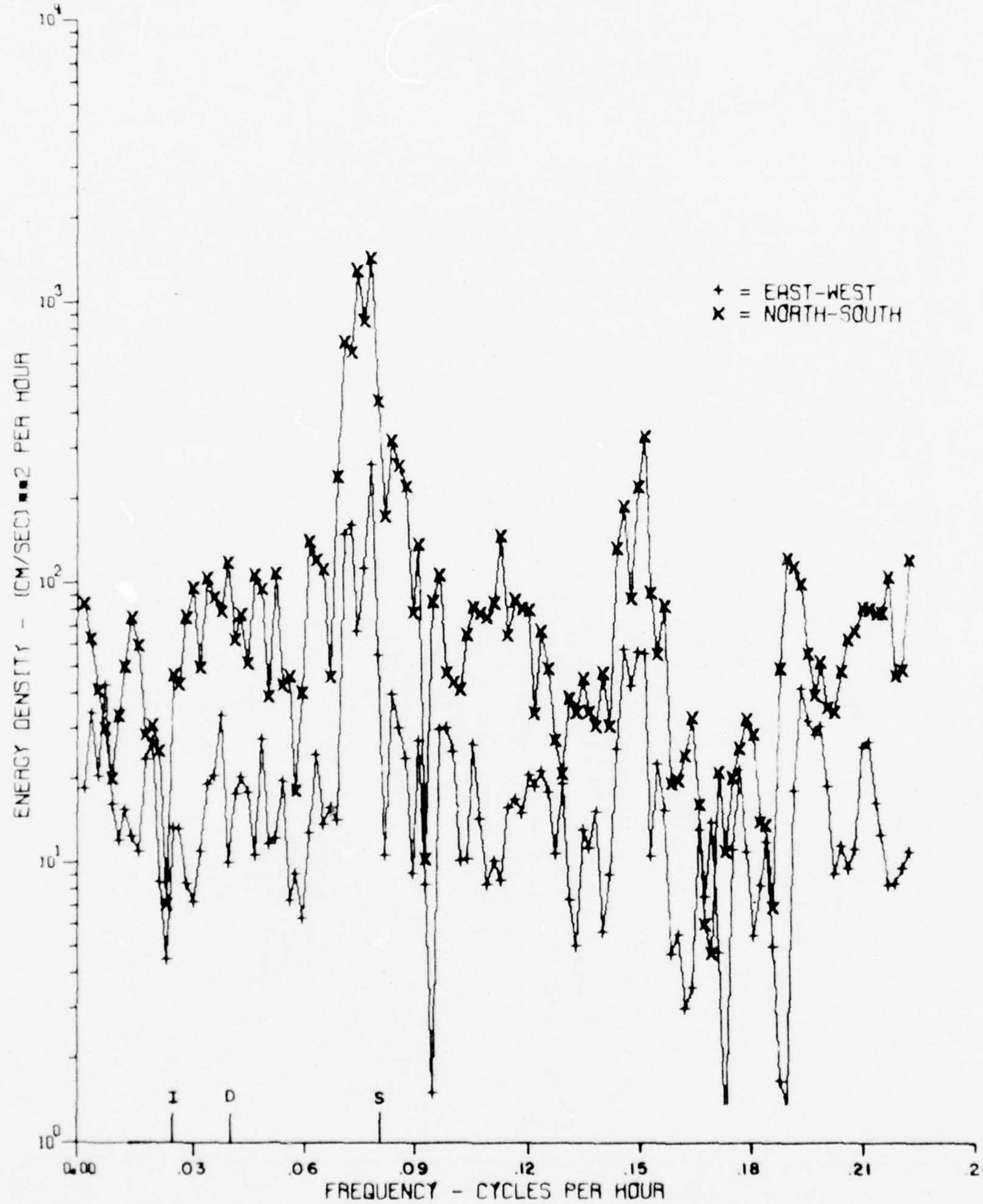


FIGURE 27 COMPONENT ENERGY SPECTRA FOR ARRAY 2 AT 1049 METERS

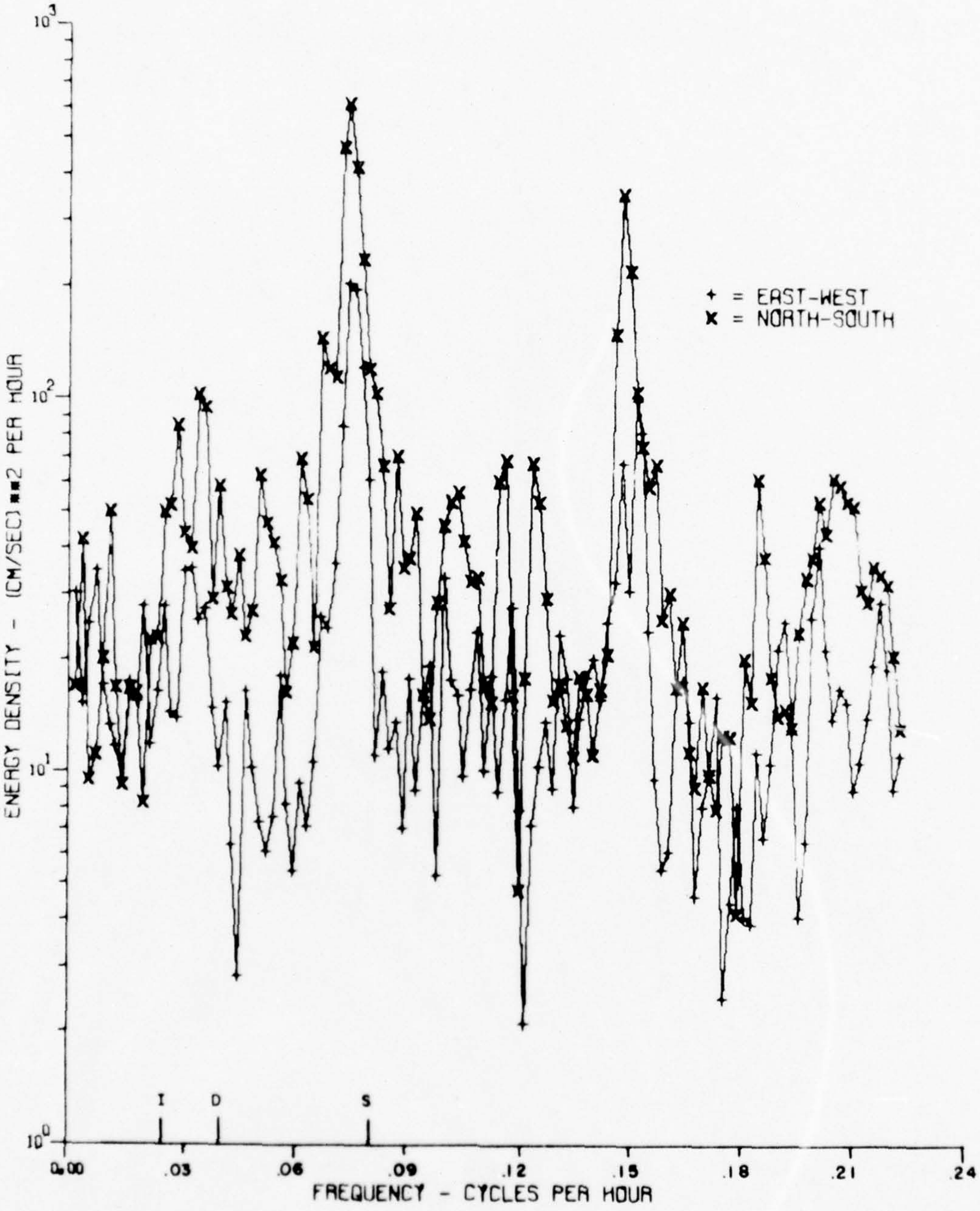


FIGURE 28 COMPONENT ENERGY SPECTRA FOR ARRAY 2 AT 1018 METERS

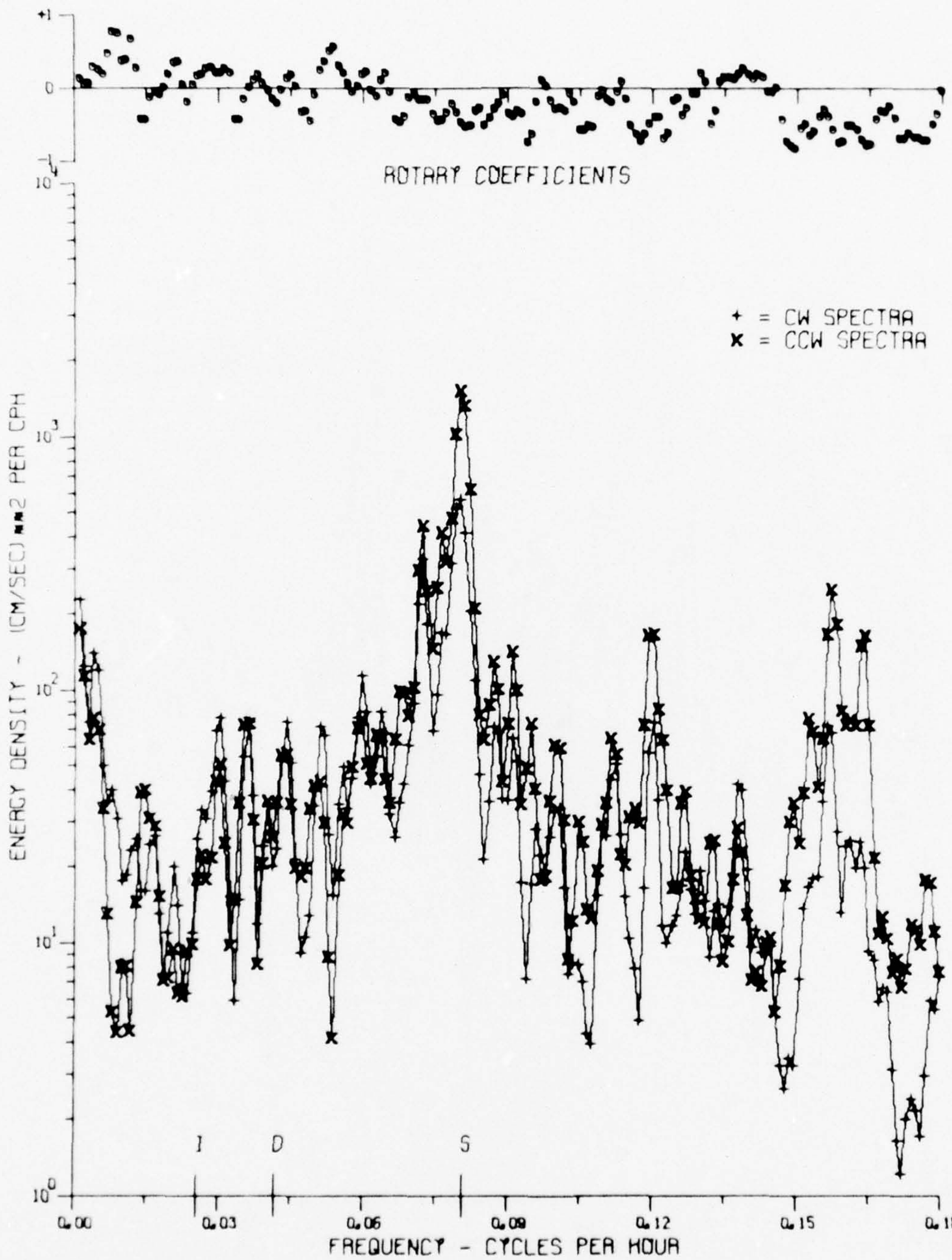


FIGURE 29 ROTARY ENERGY SPECTRA FOR ARRAY 2 AT 1064 METERS

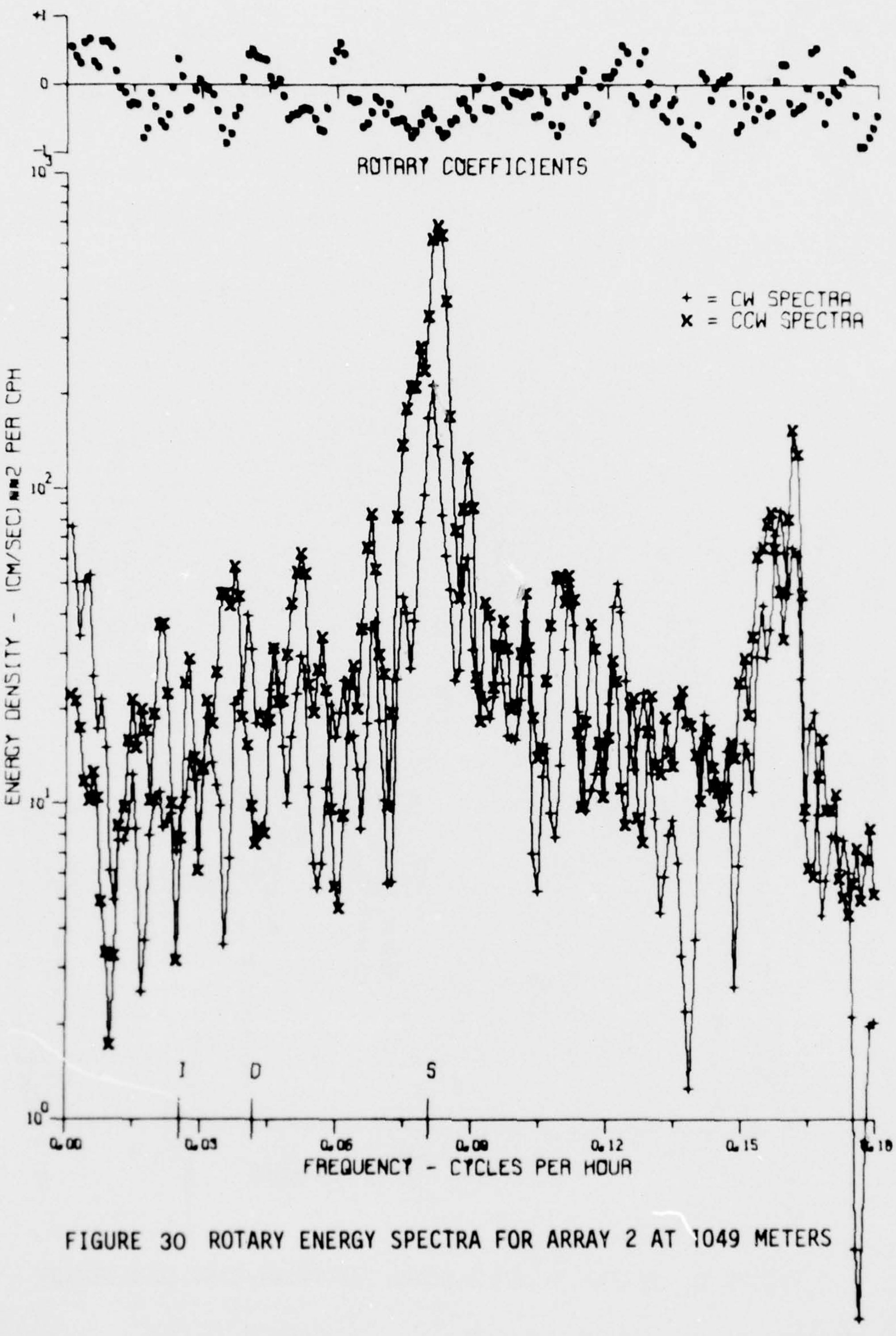


FIGURE 30 ROTARY ENERGY SPECTRA FOR ARRAY 2 AT 1049 METERS

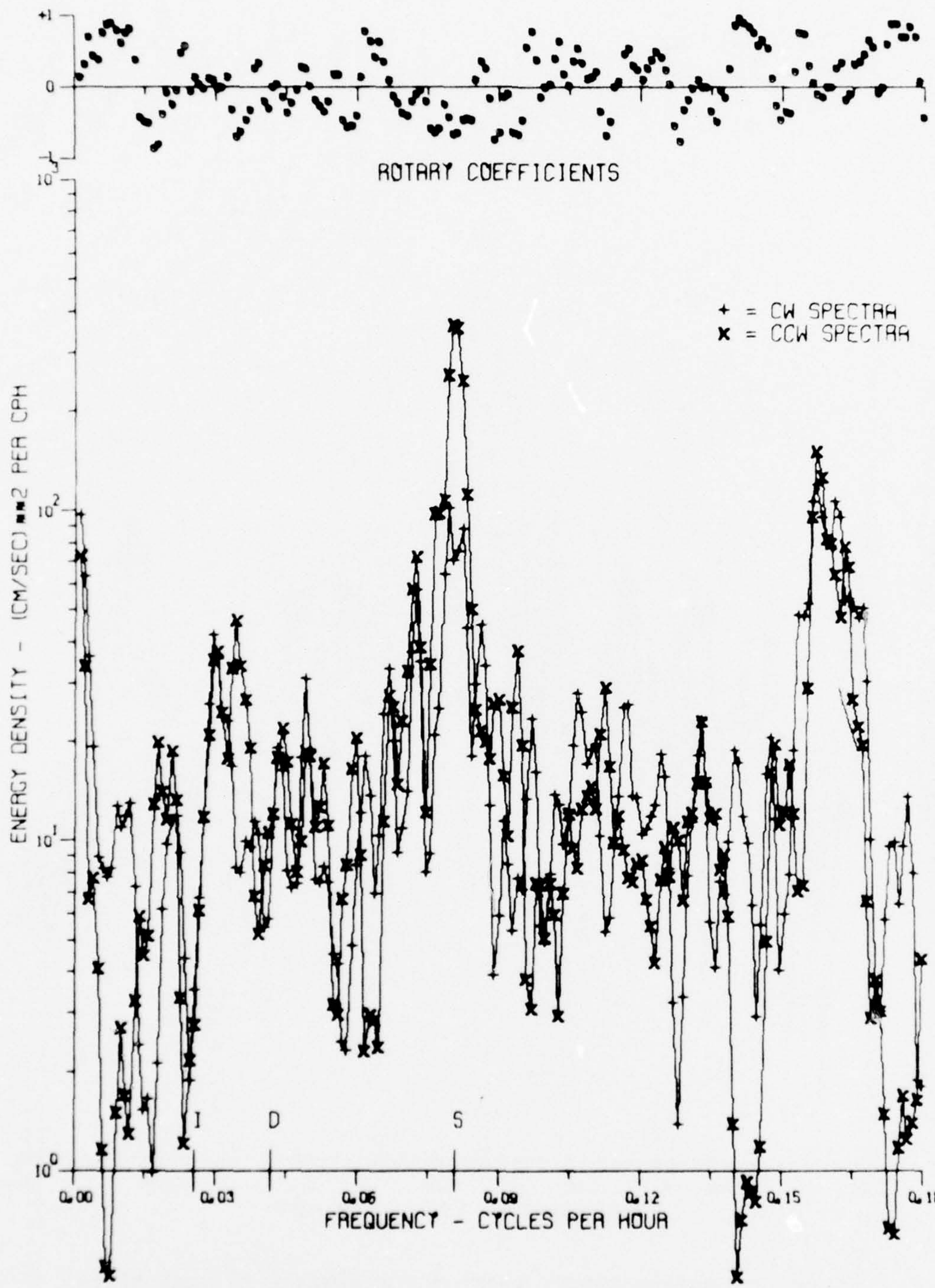


FIGURE 31 ROTARY ENERGY SPECTRA FOR ARRAY 2 AT 1018 METERS

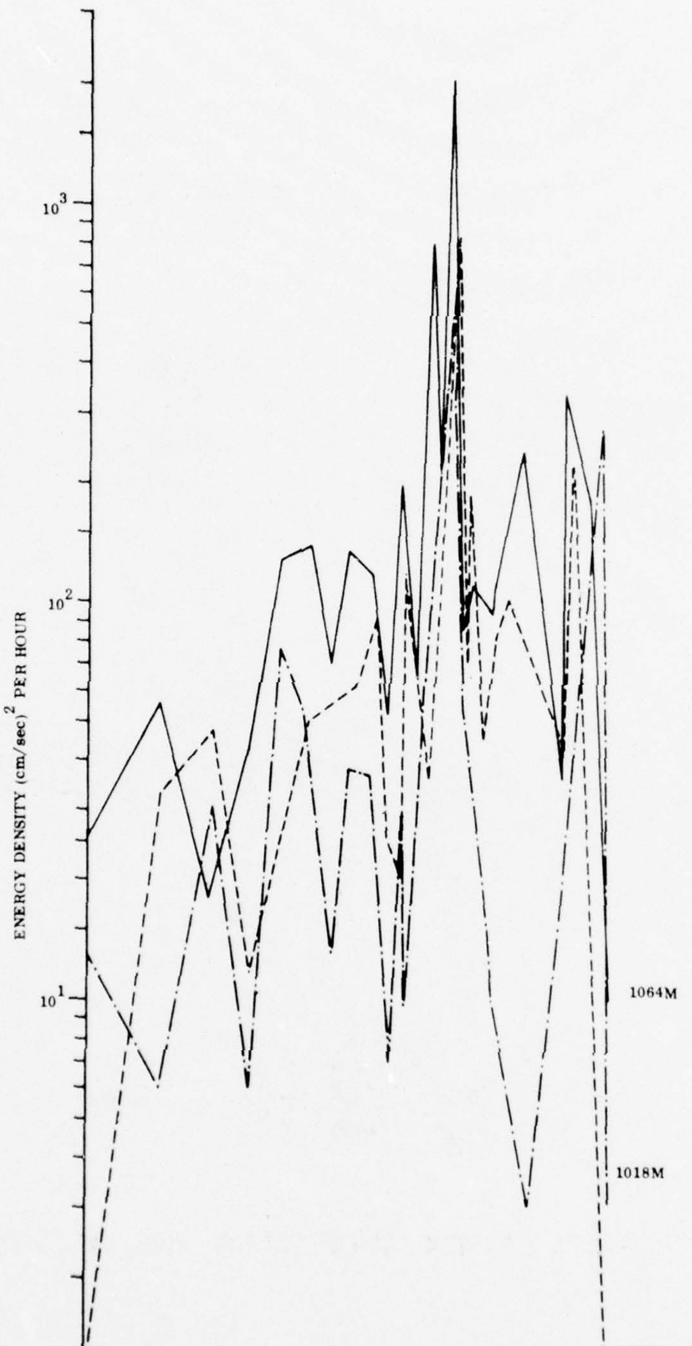


FIGURE 32 TOTAL ENERGY SPECTRA FOR ARRAY 2 AT 1064, 1049, AND 1018 METERS

ST CROIX VI ARRAY 2 FEB 1976

START TIME 0000Z 23 FEB 1976

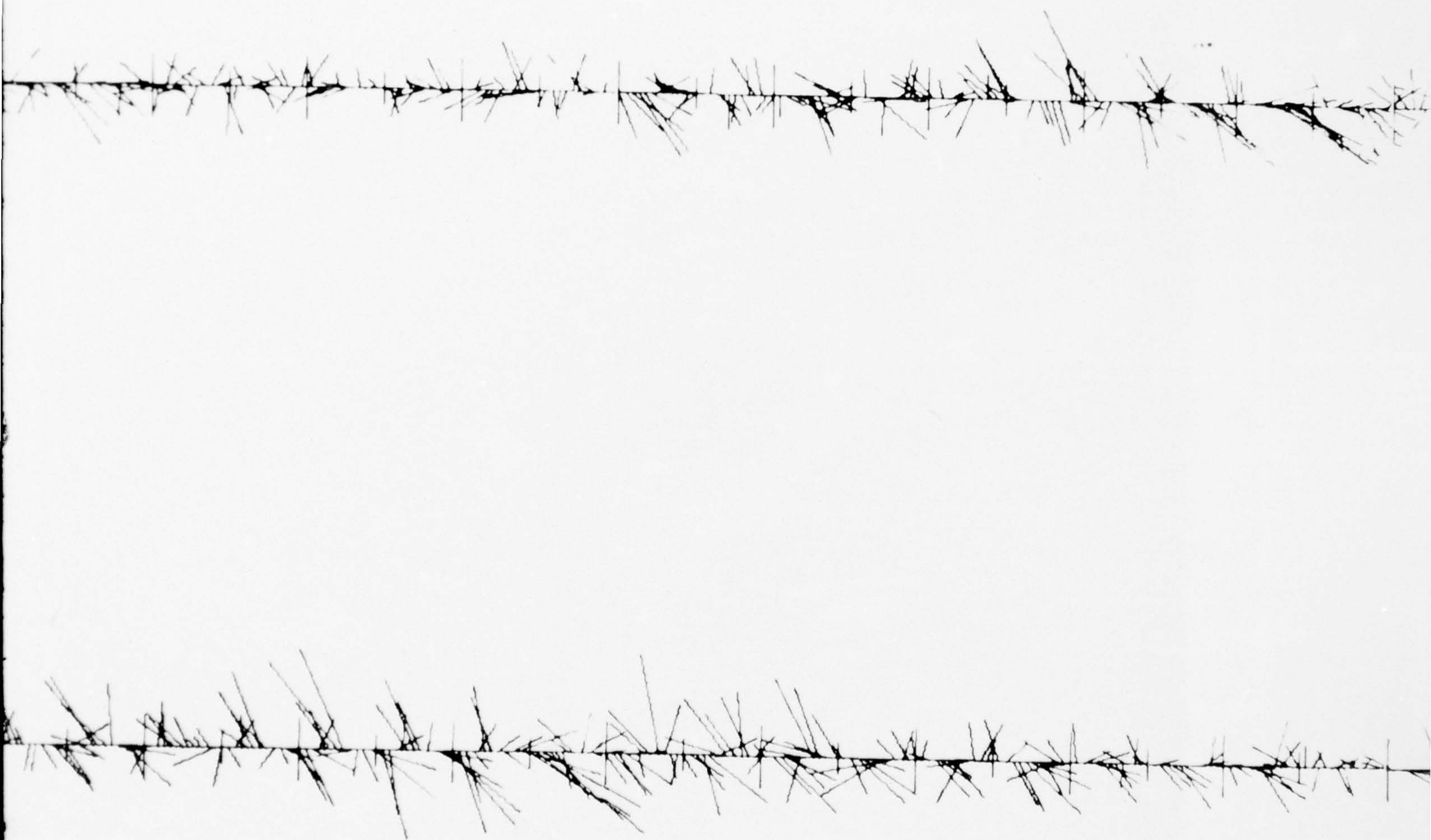
ONE HOUR AVERAGES

CURRENT METER	DEPTH - METERS
VACM-295	1064
VACM-252	1049
VACM-253	1018

SCALE = 10 CM/SEC PER CM 0 5 10 15 20 25 30 35 40 45 50

FIGURE 33 TIME SERIES VECTOR PLOT, ARRAY 2


DEPTH
(METERS)
START TIME 0000Z 25 FEB 1976
762
12
HOURS
747



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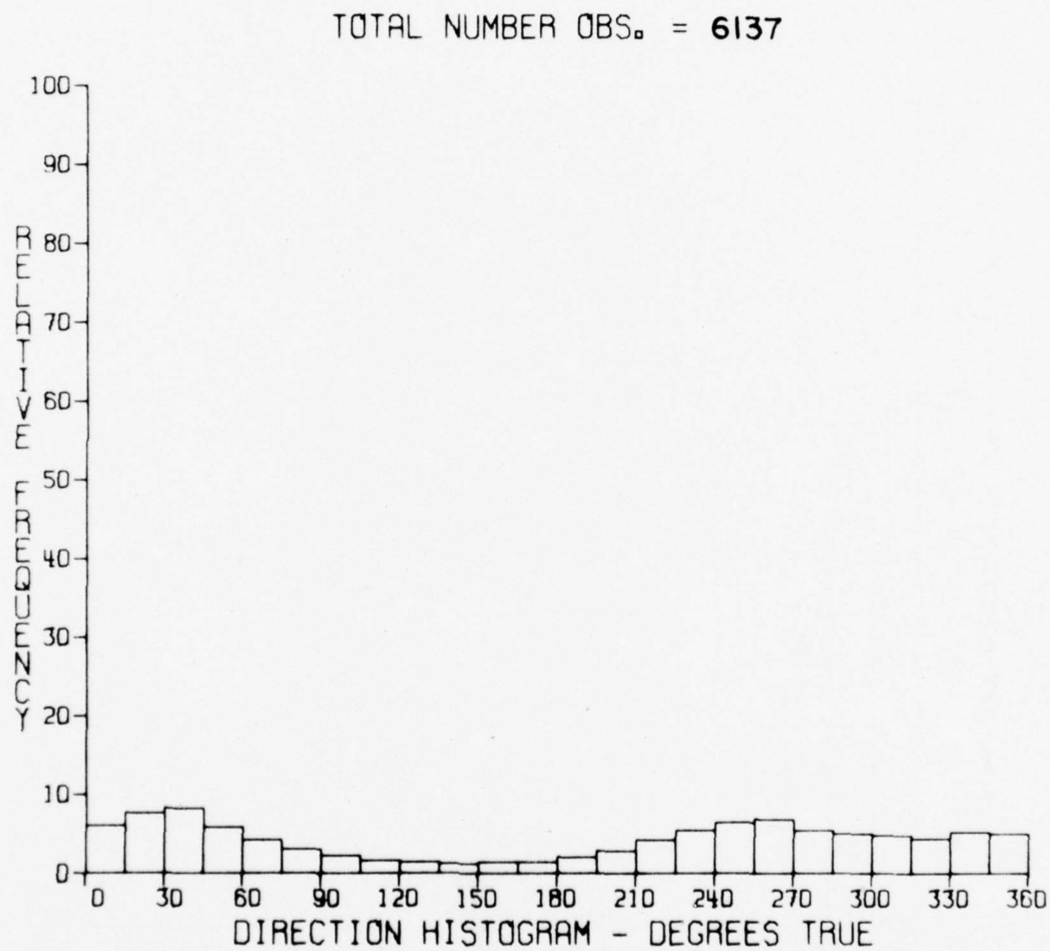

FIGURE 34 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 3 AT 963 METERS

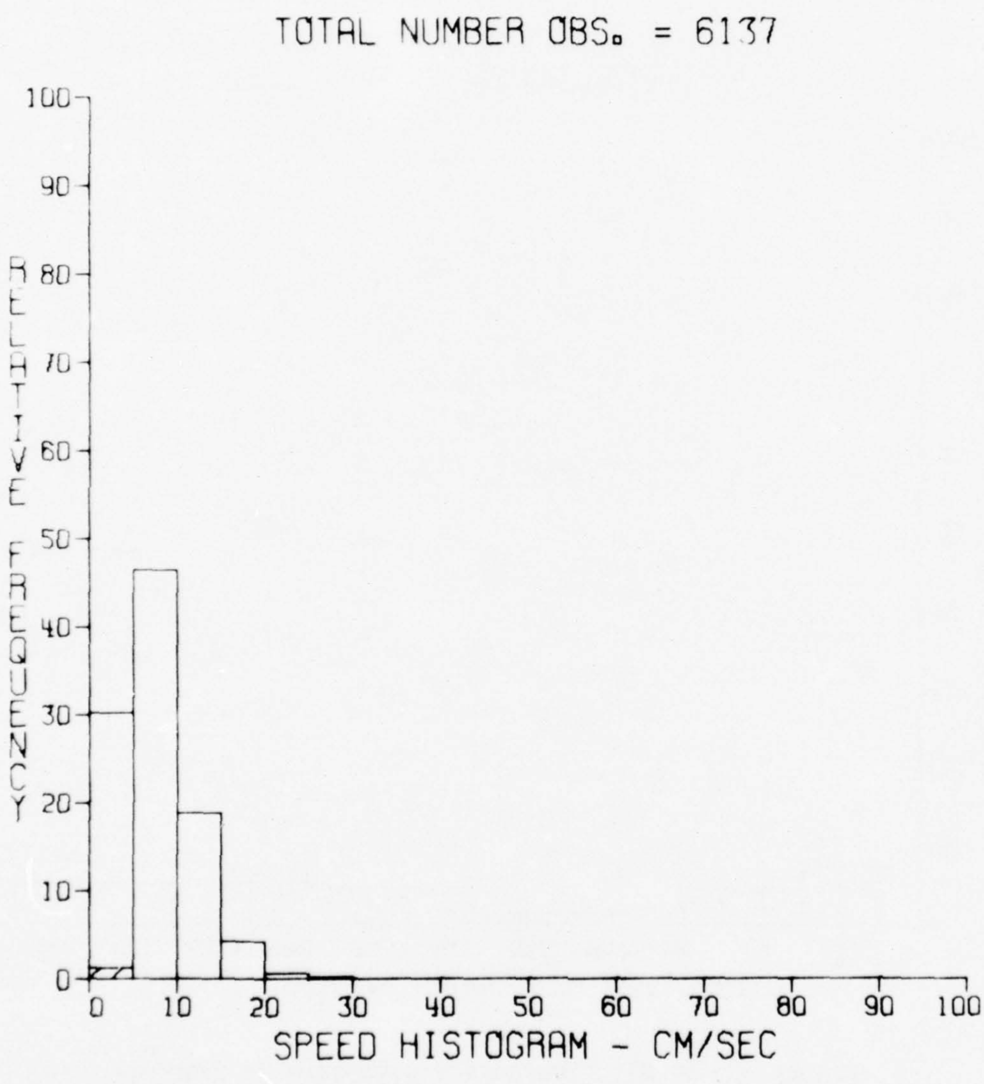

FIGURE 35 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 3 AT 963 METERS

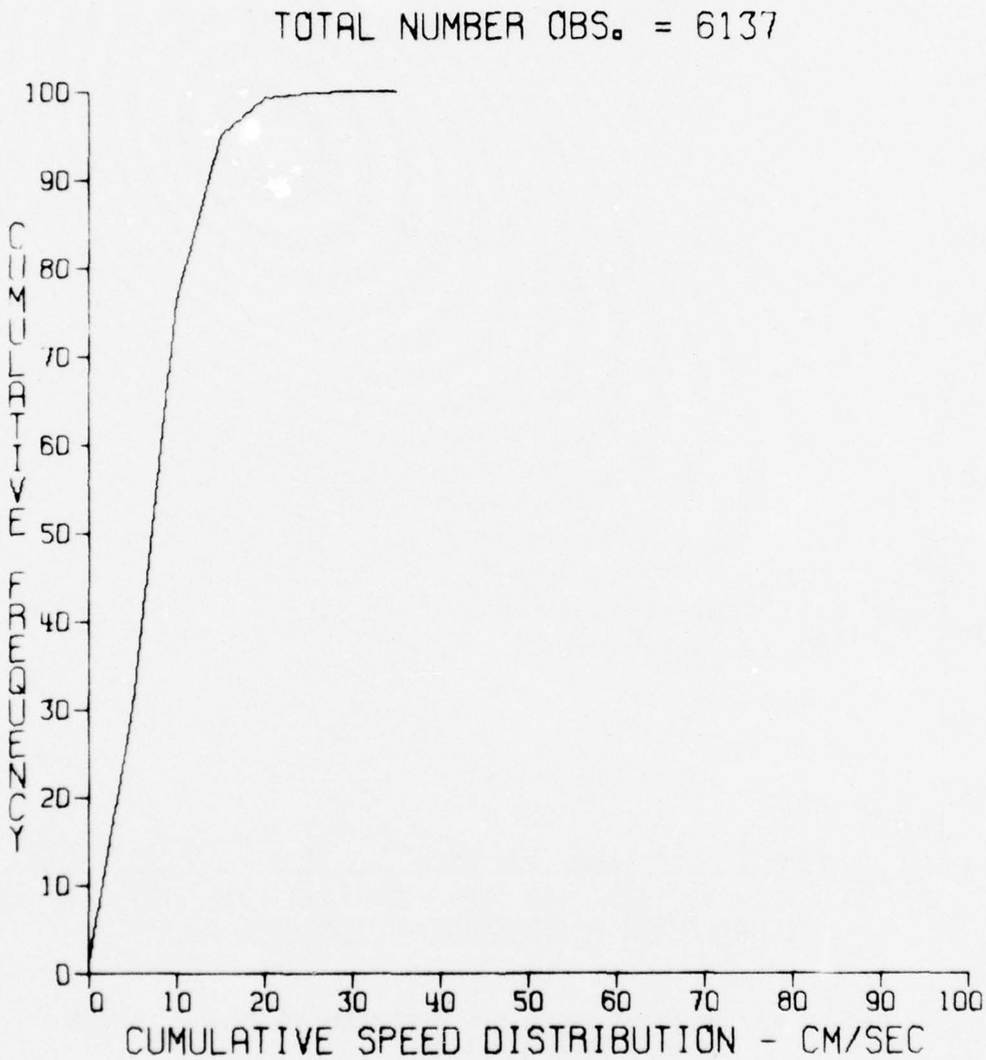

FIGURE 36 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 3 AT 963 METERS

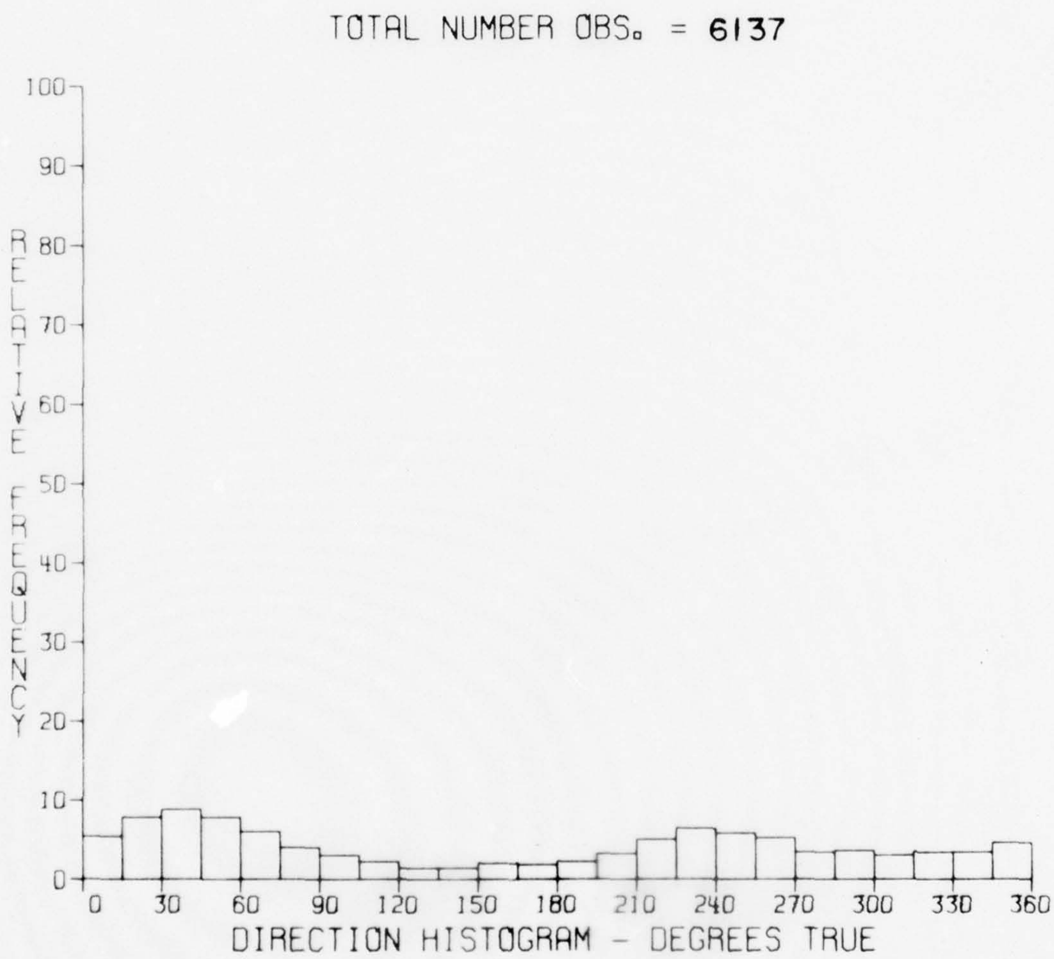

FIGURE 37 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 3 AT 948 METERS

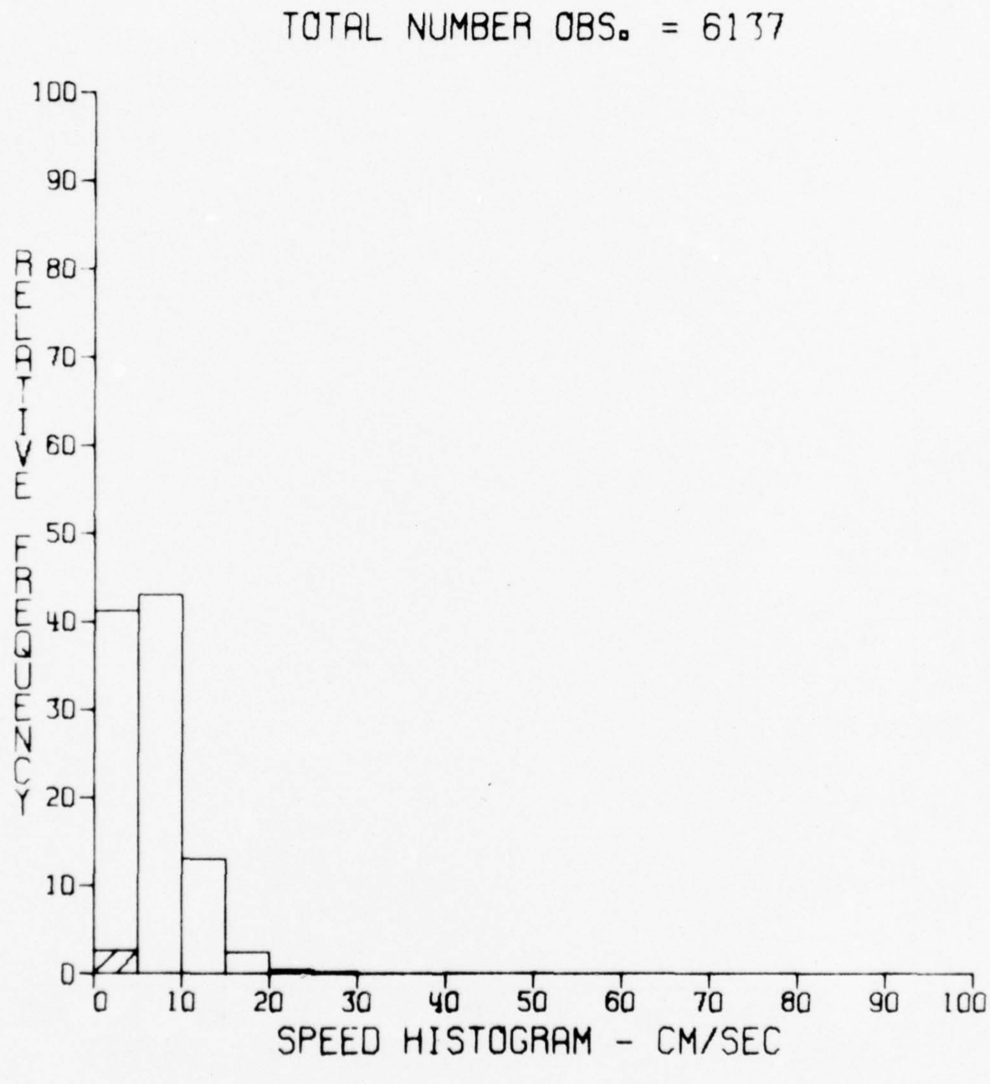

FIGURE 38 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 3 AT 948 METERS

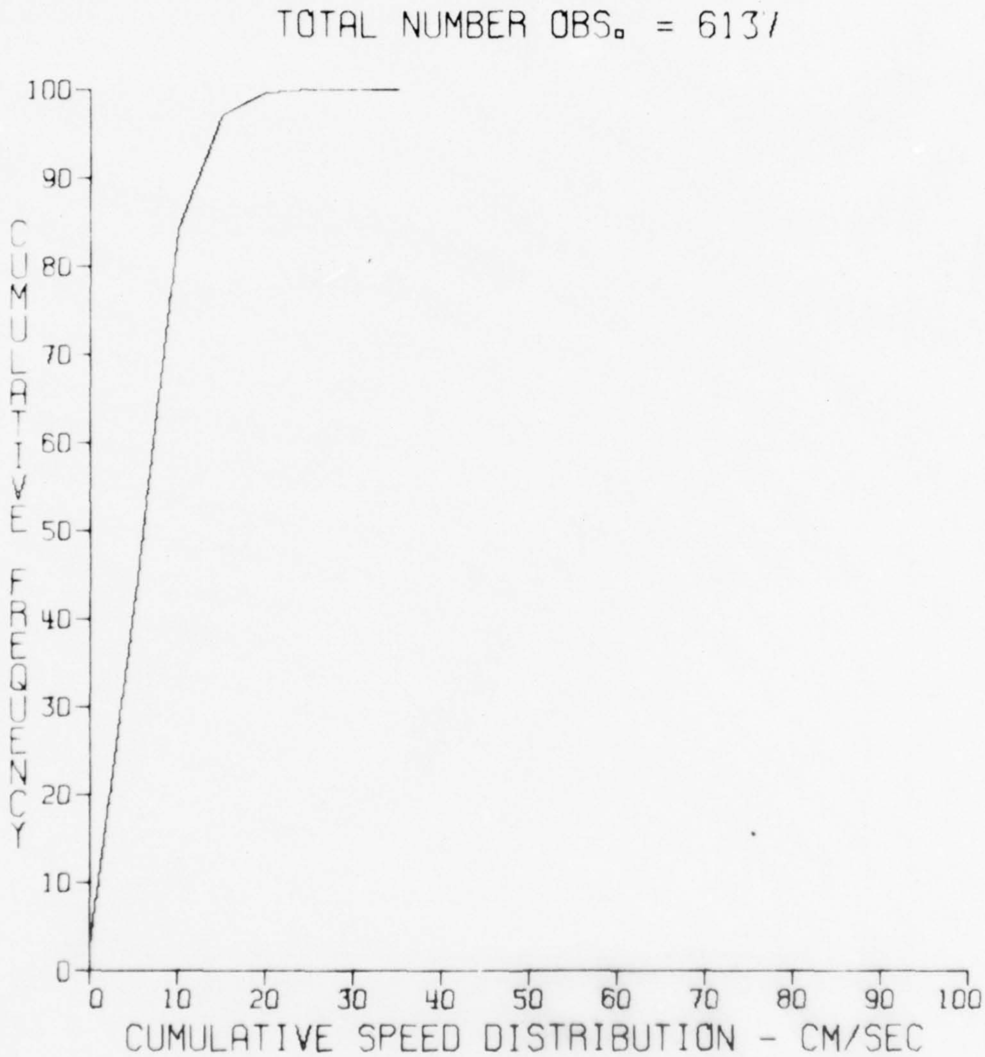

FIGURE 39 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 3 AT 948 METERS

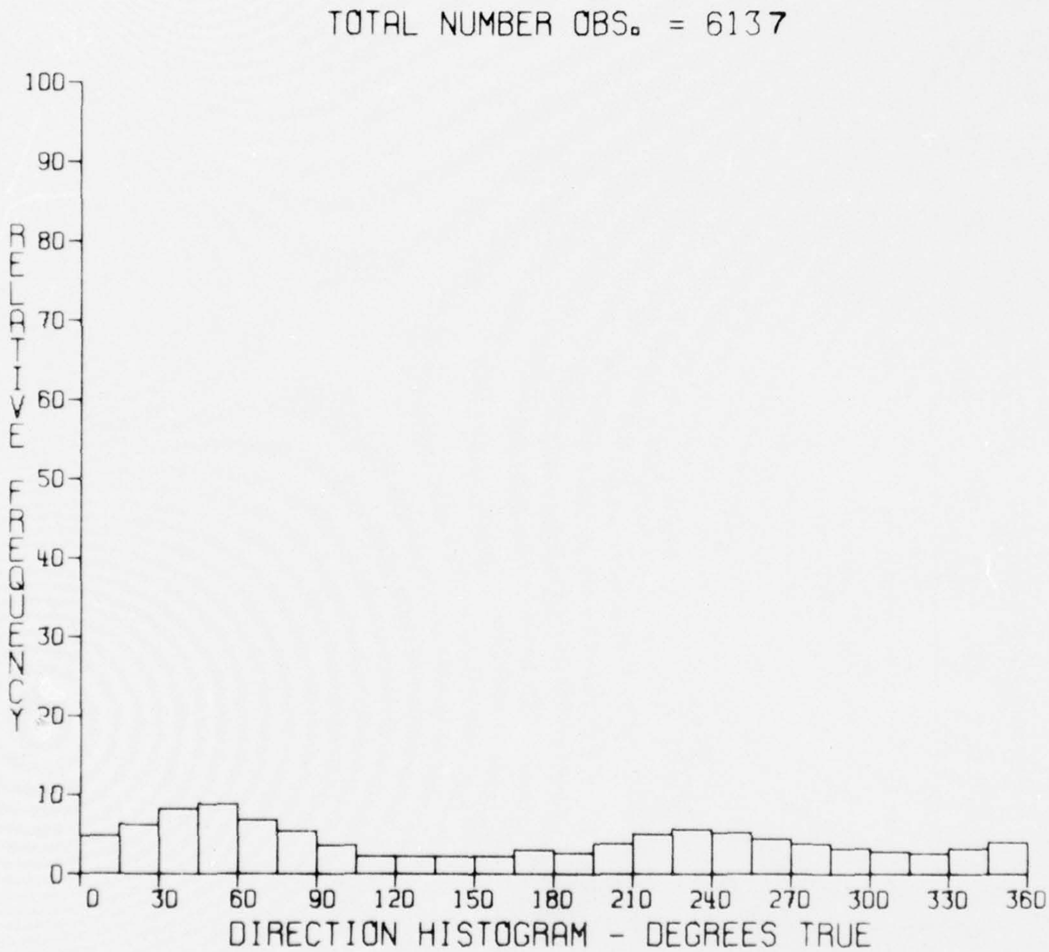

FIGURE 40 RELATIVE FREQUENCY HISTOGRAM OF DIRECTION FOR ARRAY 3 AT 917 METERS

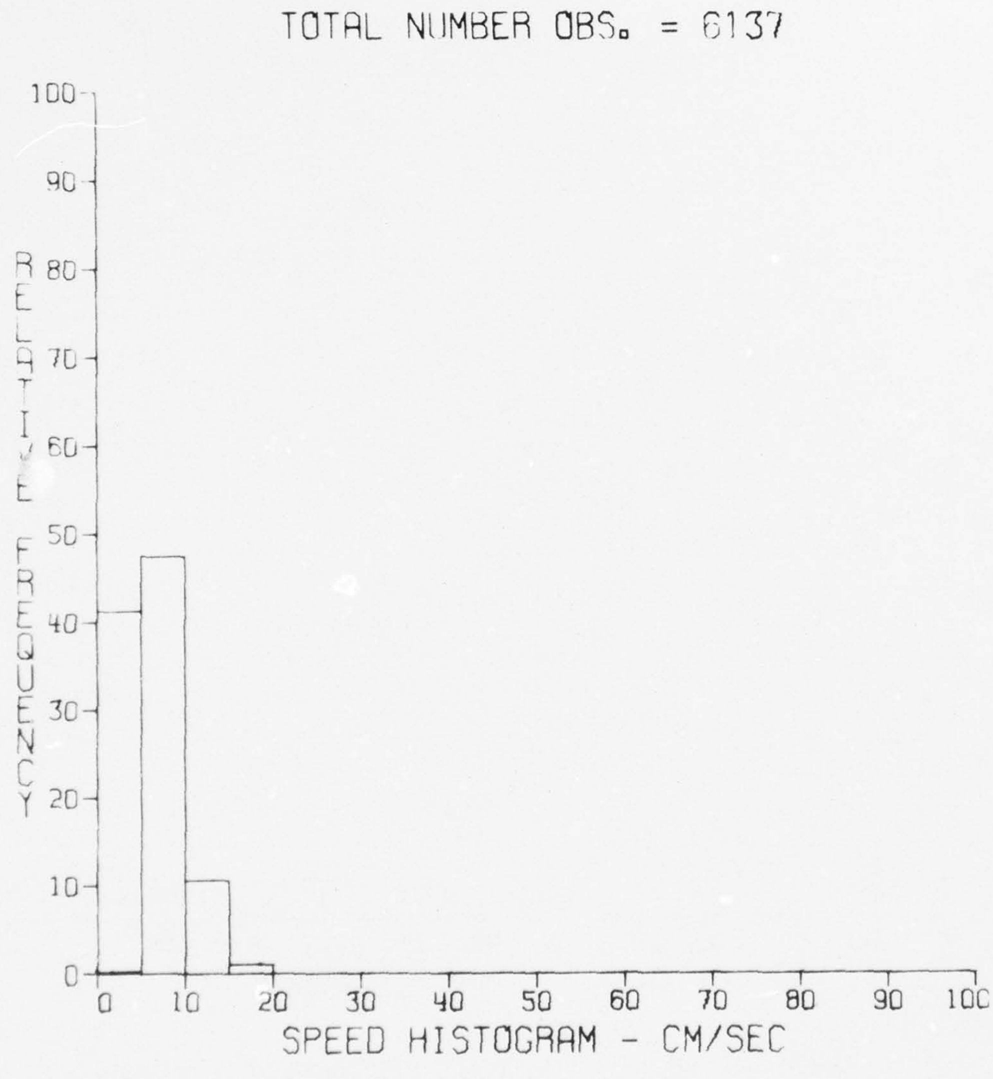

FIGURE 41 RELATIVE FREQUENCY HISTOGRAM OF SPEED FOR ARRAY 3 AT 917 METERS

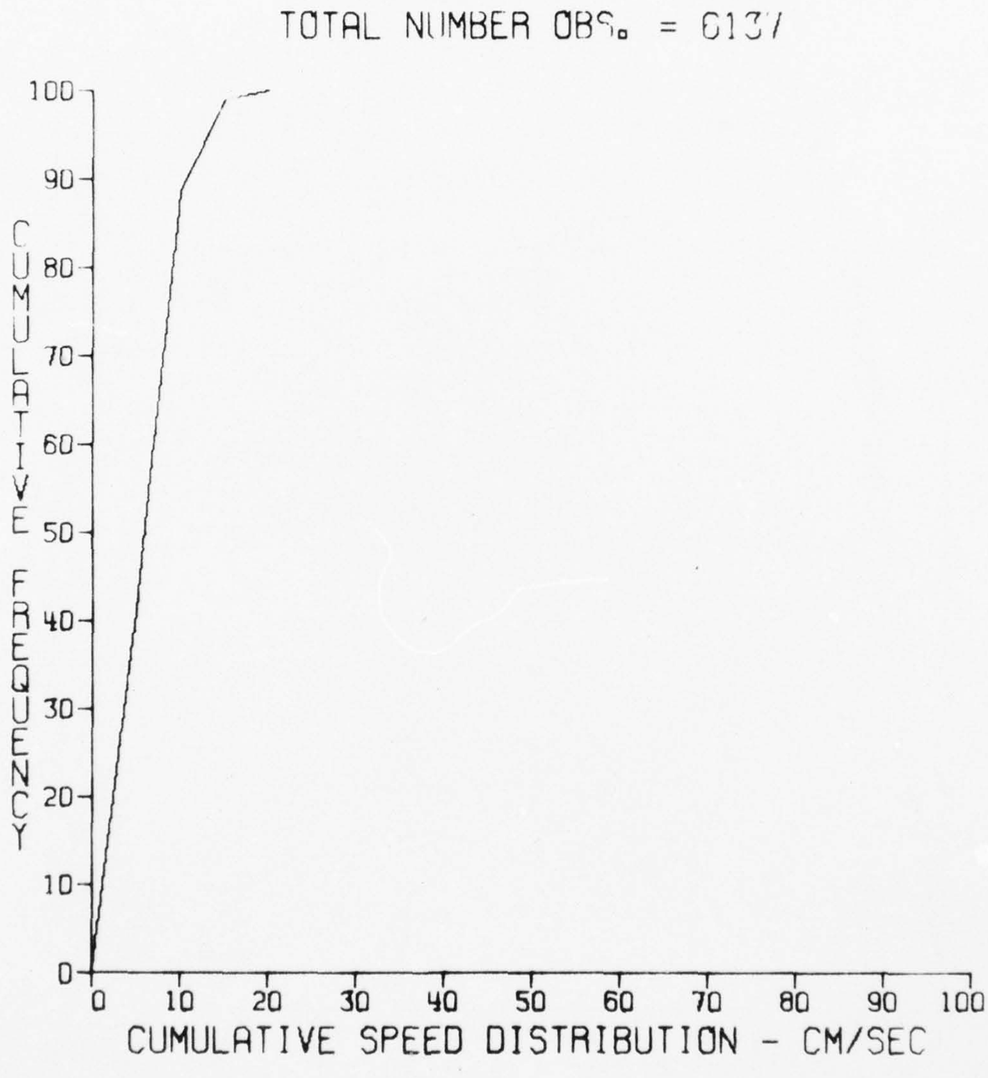

FIGURE 42 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 3 AT 917 METERS

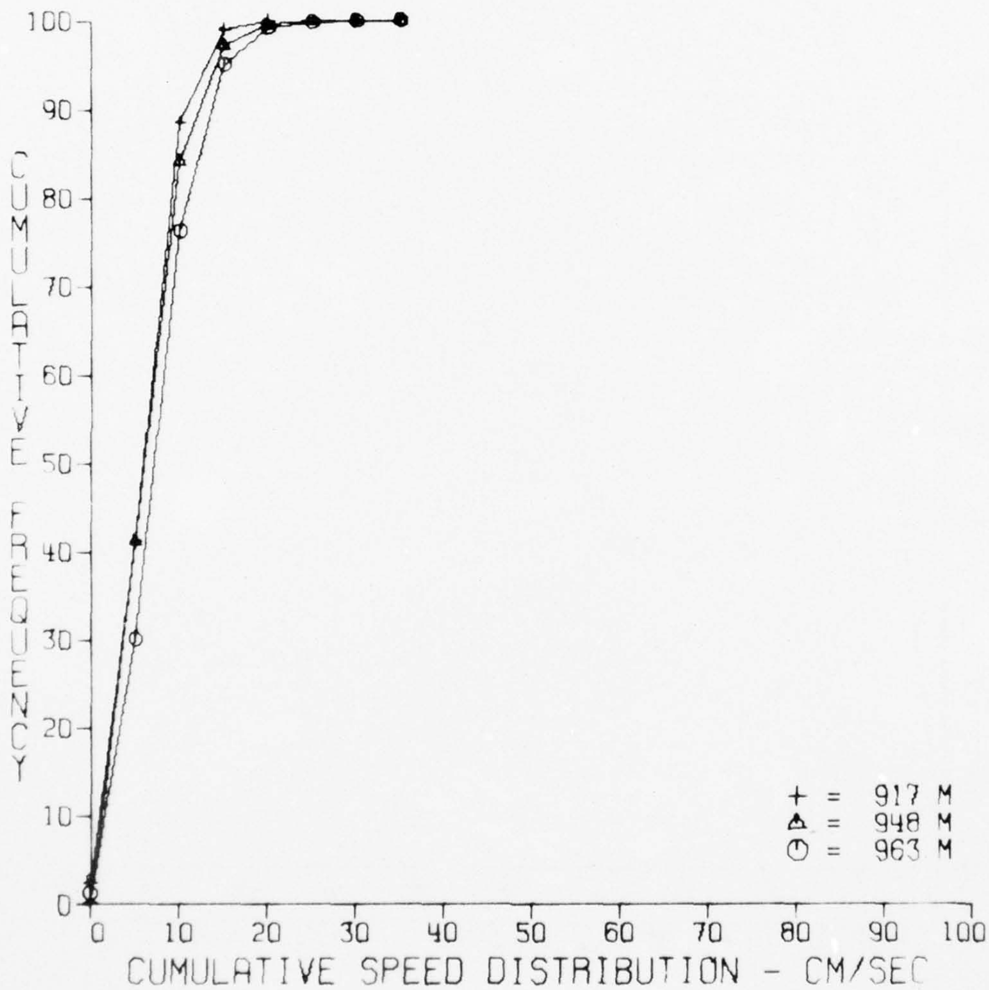

FIGURE 43 CUMULATIVE FREQUENCY DISTRIBUTION OF SPEED FOR ARRAY 3 AT 963, 948, AND 917 METERS

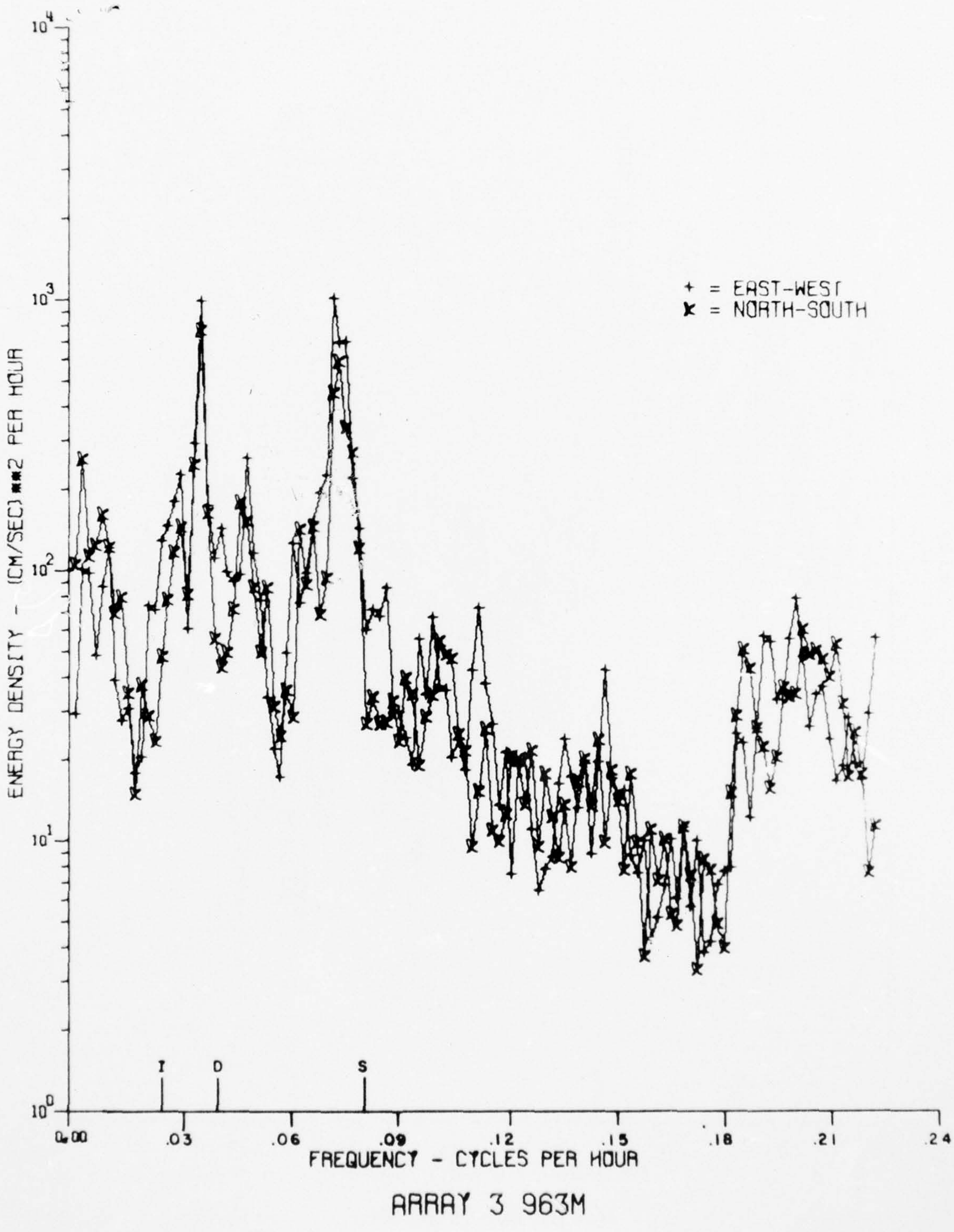

FIGURE 44 COMPONENT ENERGY SPECTRA FOR ARRAY 3 AT 963 METERS

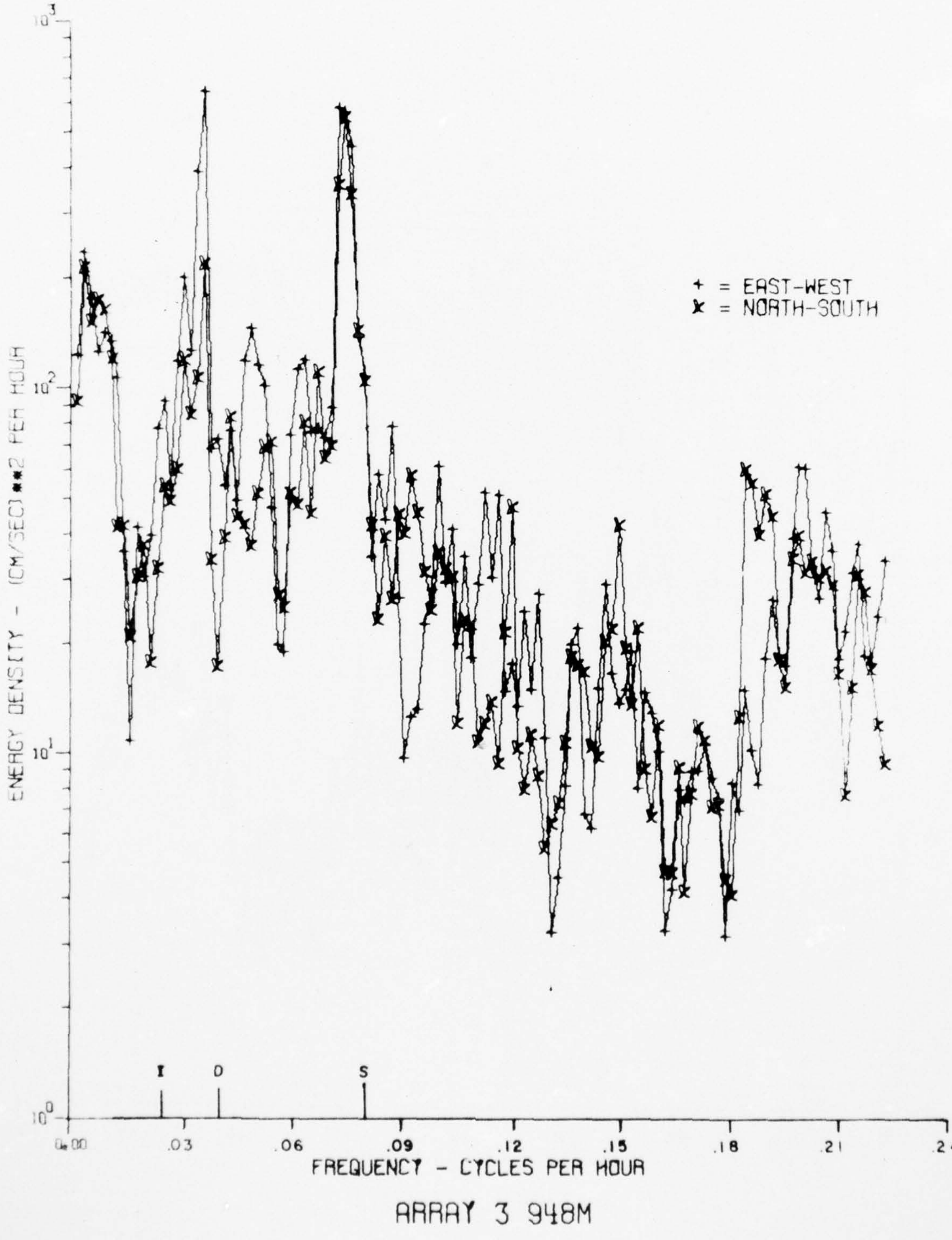

FIGURE 45 COMPONENT ENERGY SPECTRA FOR ARRAY 3 AT 948 METERS

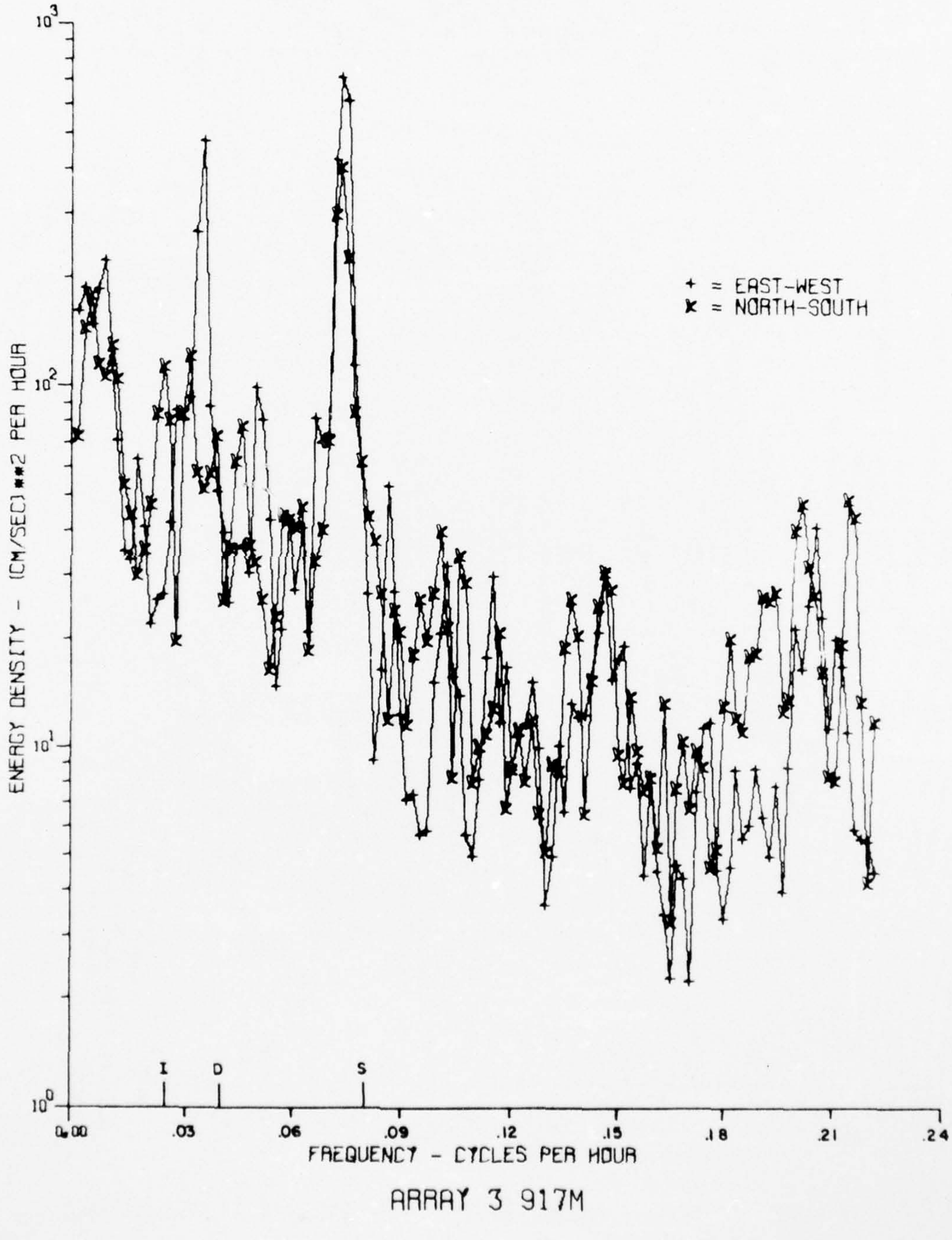

FIGURE 46 COMPONENT ENERGY SPECTRA FOR ARRAY 3 AT 917 METERS

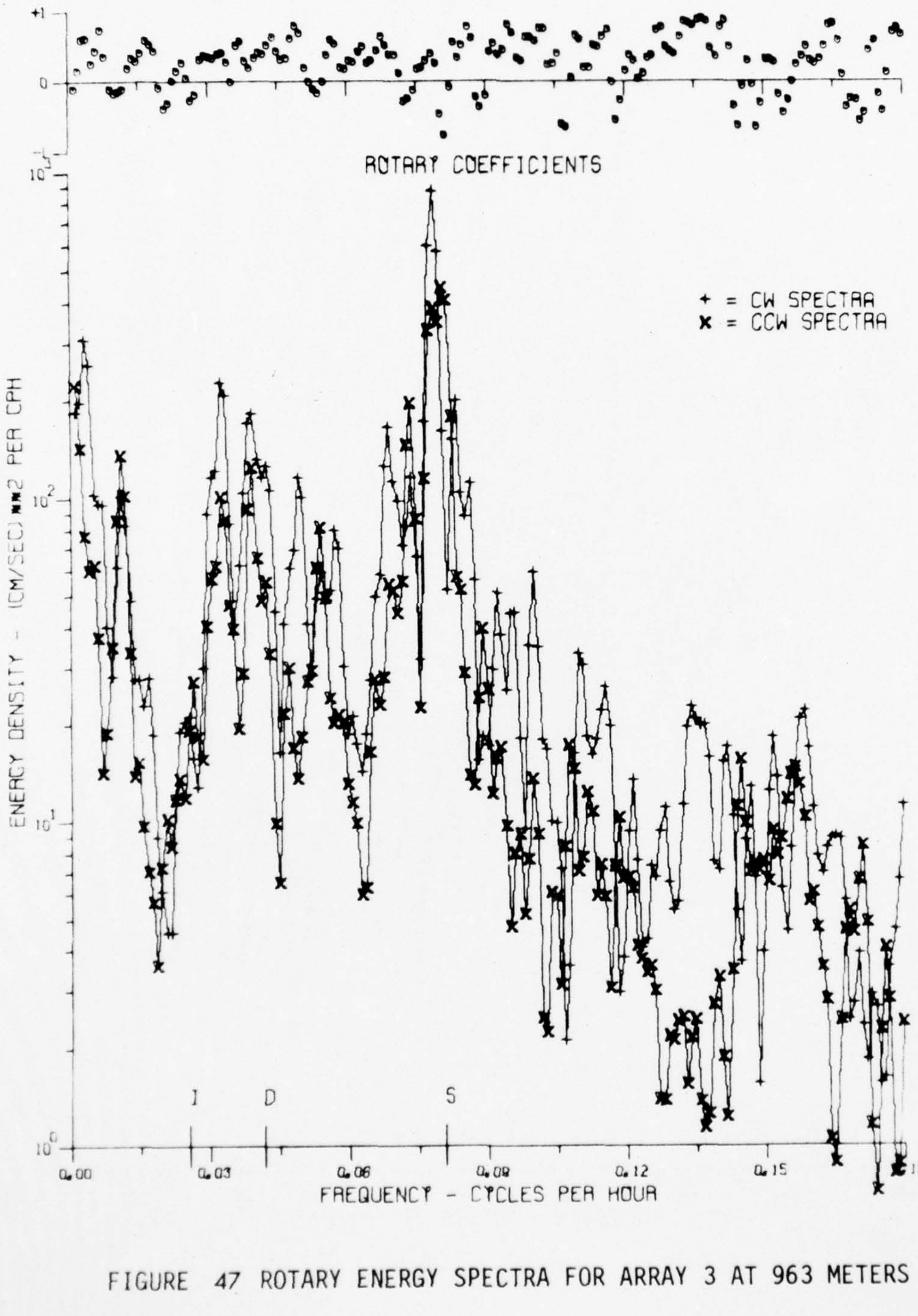

FIGURE 47 ROTARY ENERGY SPECTRA FOR ARRAY 3 AT 963 METERS

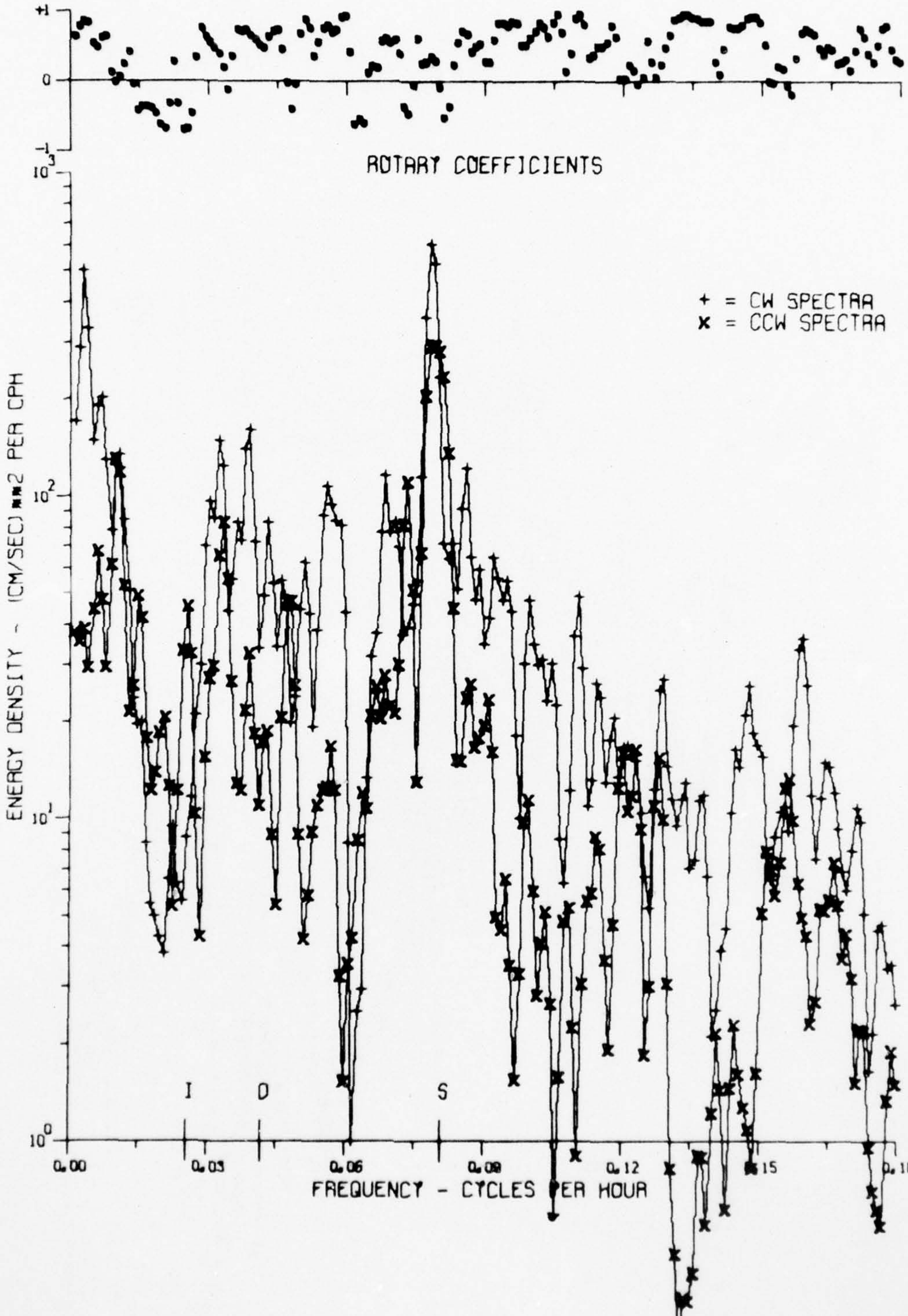

FIGURE 48 ROTARY ENERGY SPECTRA FOR ARRAY 3 AT 948 METERS

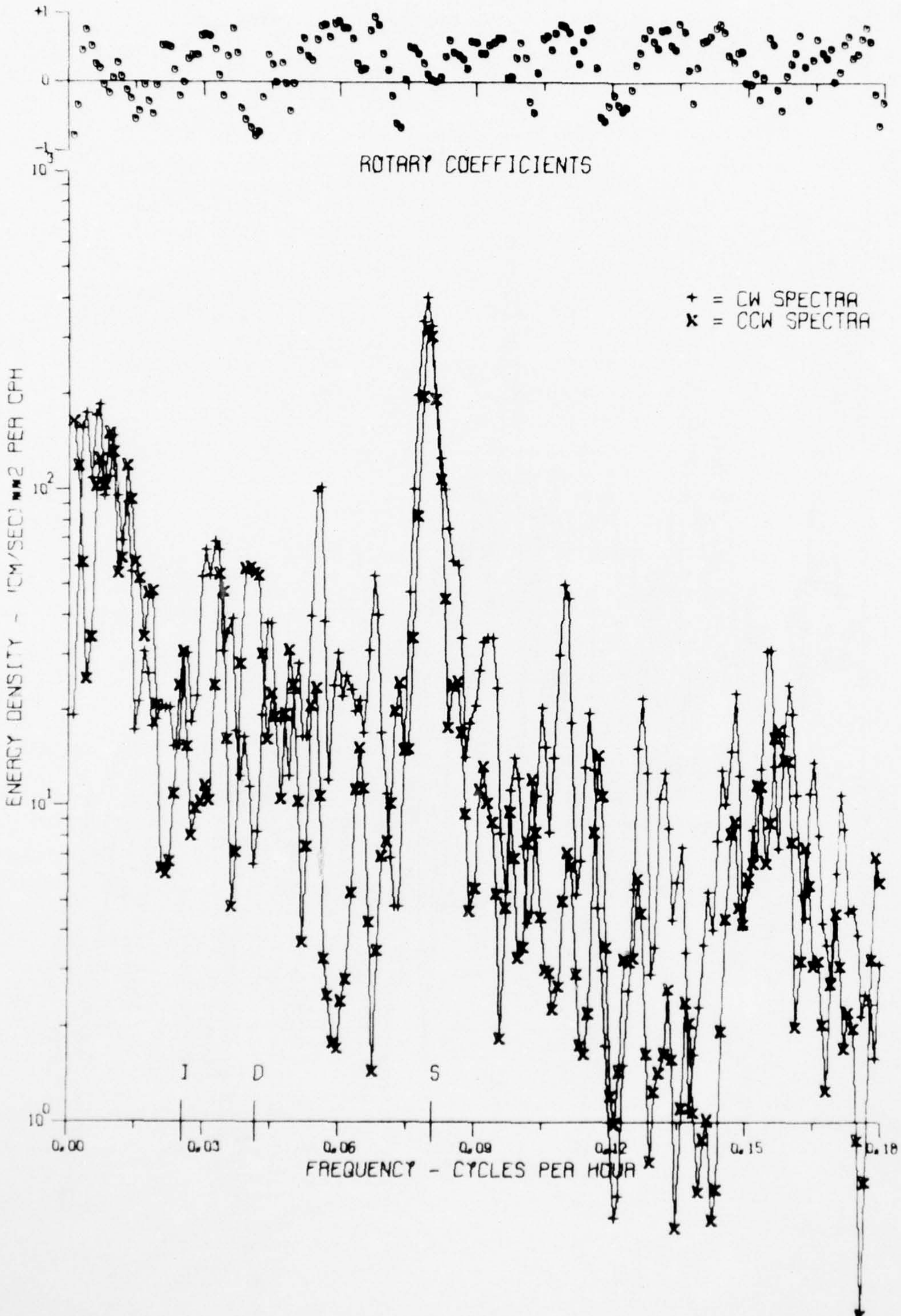

FIGURE 49 ROTARY ENERGY SPECTRA FOR ARRAY 3 AT 917 METERS

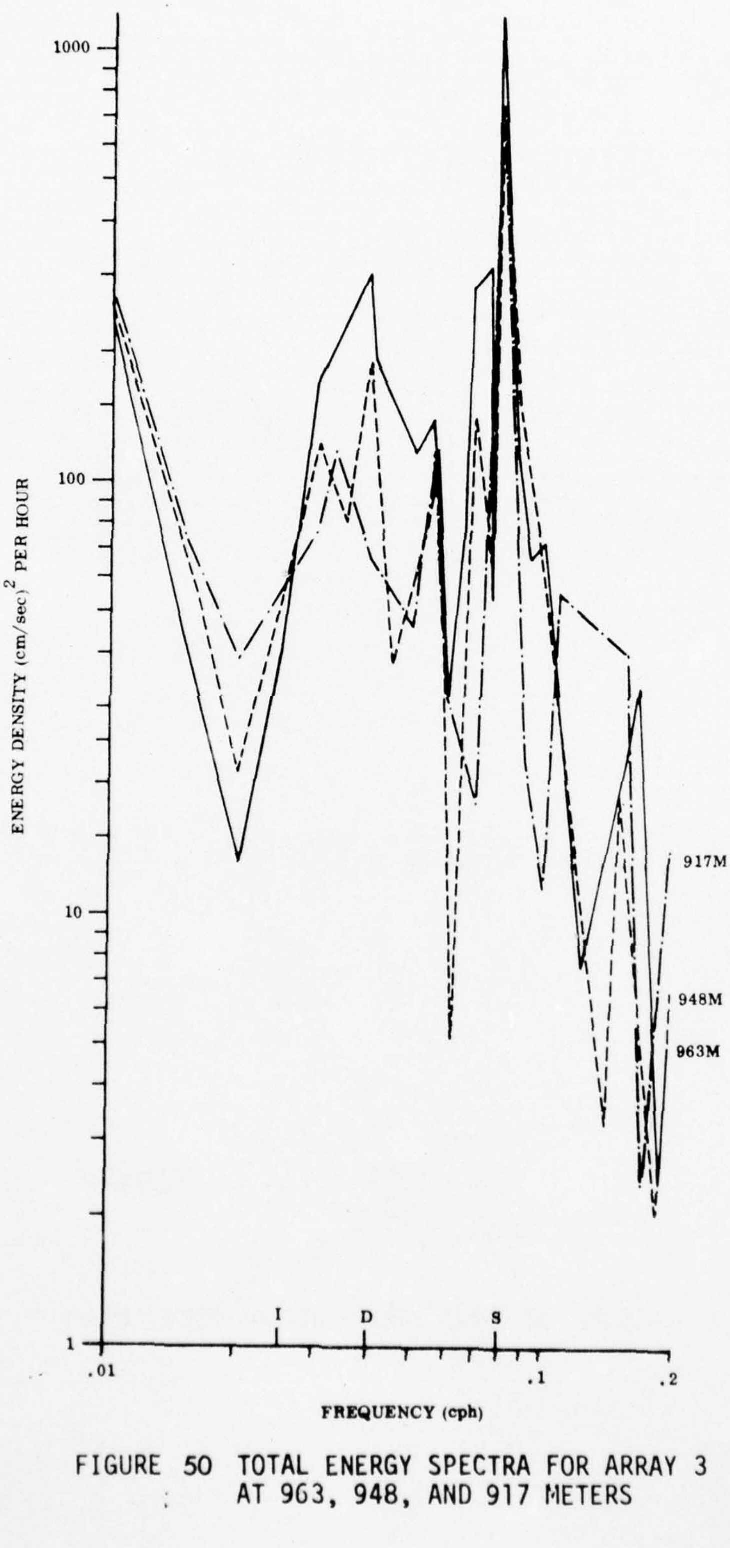

FIGURE 50 TOTAL ENERGY SPECTRA FOR ARRAY 3
AT 963, 948, AND 917 METERS

ST CROIX VI ARRAY 3 FEB 1976

START TIME 0000Z 25 FEB 1976

ONE HOUR AVERAGES

CURRENT METER	DEPTH - METERS
VACM-290	963
VACM-294	948
VACM-293	917

SCALE = 10 CM/SEC PER CM 0 5 10 15 20 25 30 35 40 45 50

FIGURE 51 TIME SERIES VECTOR PLOT, ARRAY 3


START TIME 0000Z 25 FEB 1976
DEPTH (METERS)
963
12 HOURS
948
917

AD-A043 654 NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY BAY ST--ETC F/G 8/3
THE OCEANOGRAPHIC/METEOROLOGICAL ENVIRONMENT WEST OF ST. CROIX,(U)
JUL 77 D A BURNS
UNCLASSIFIED NORDA-13 CHES/NAVFAC-FPO-1-77(14) NL

2 OF 2
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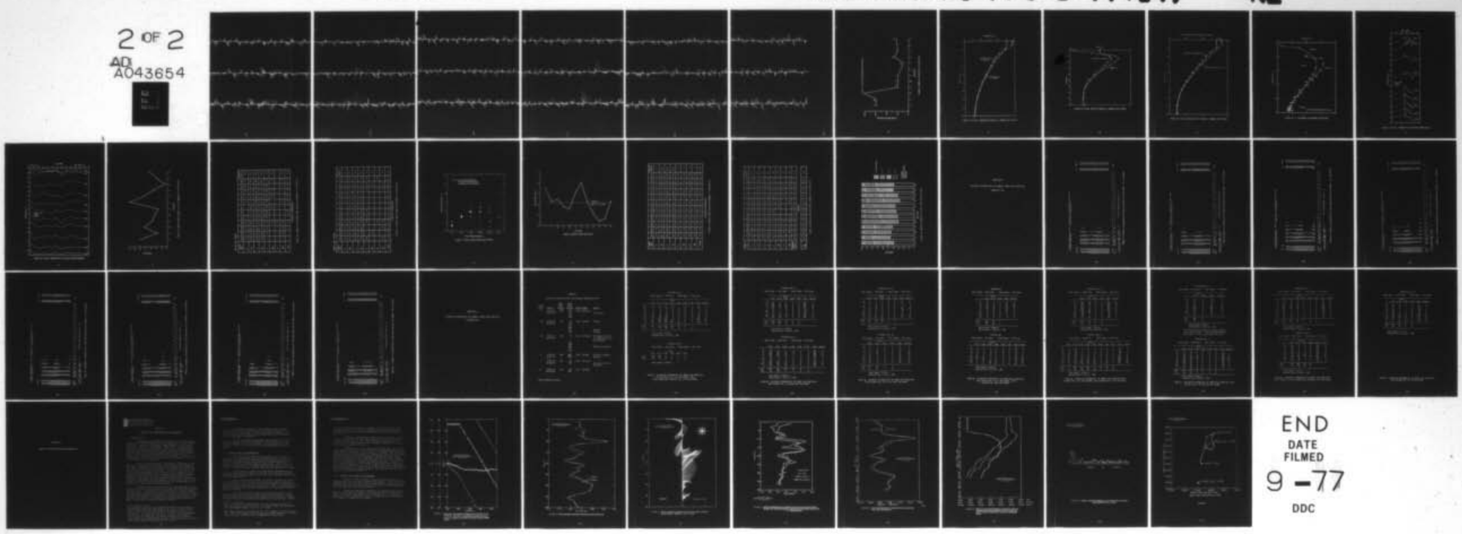
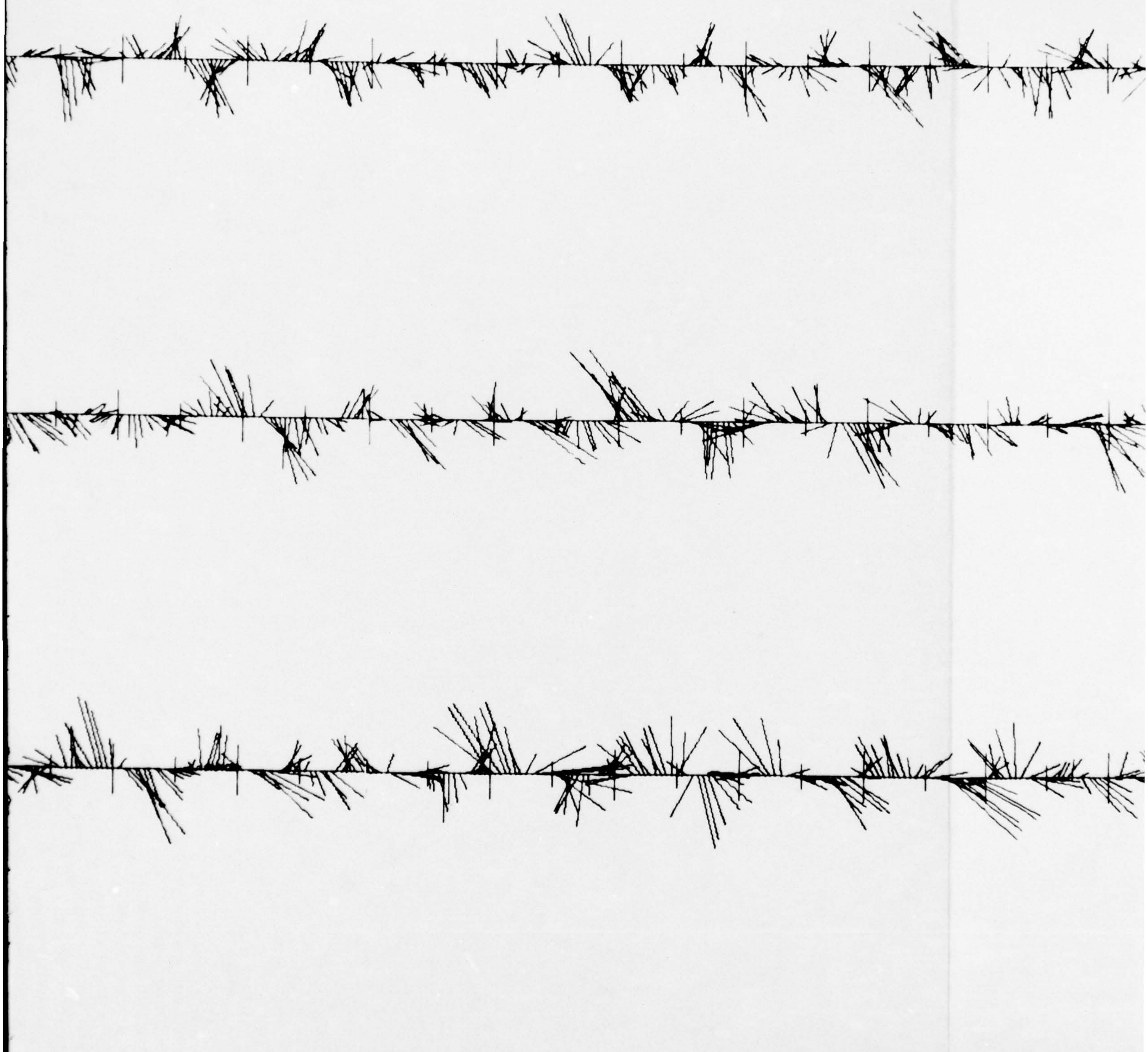
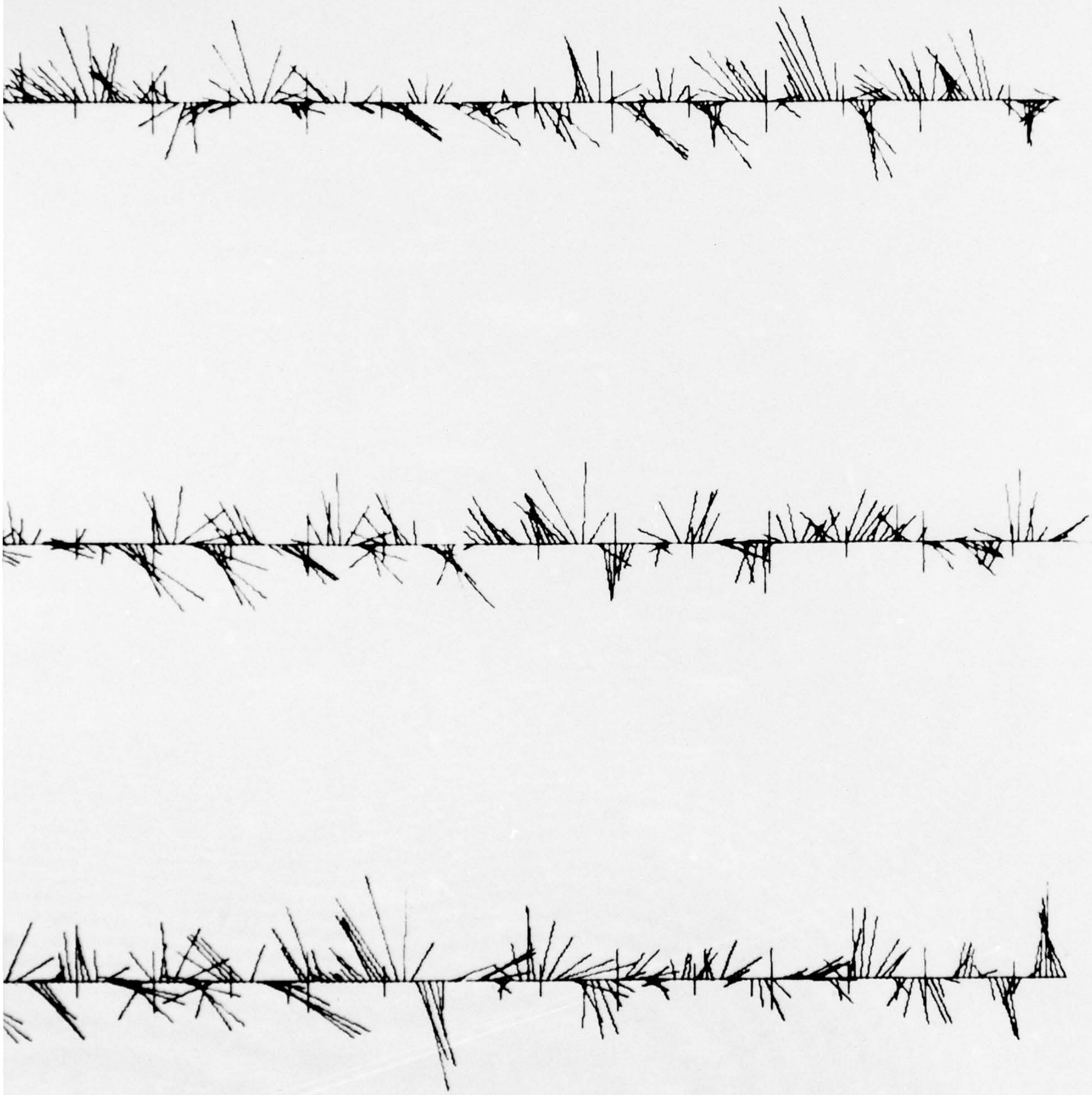
A043654



END
DATE
FILMED
9-77
DDC





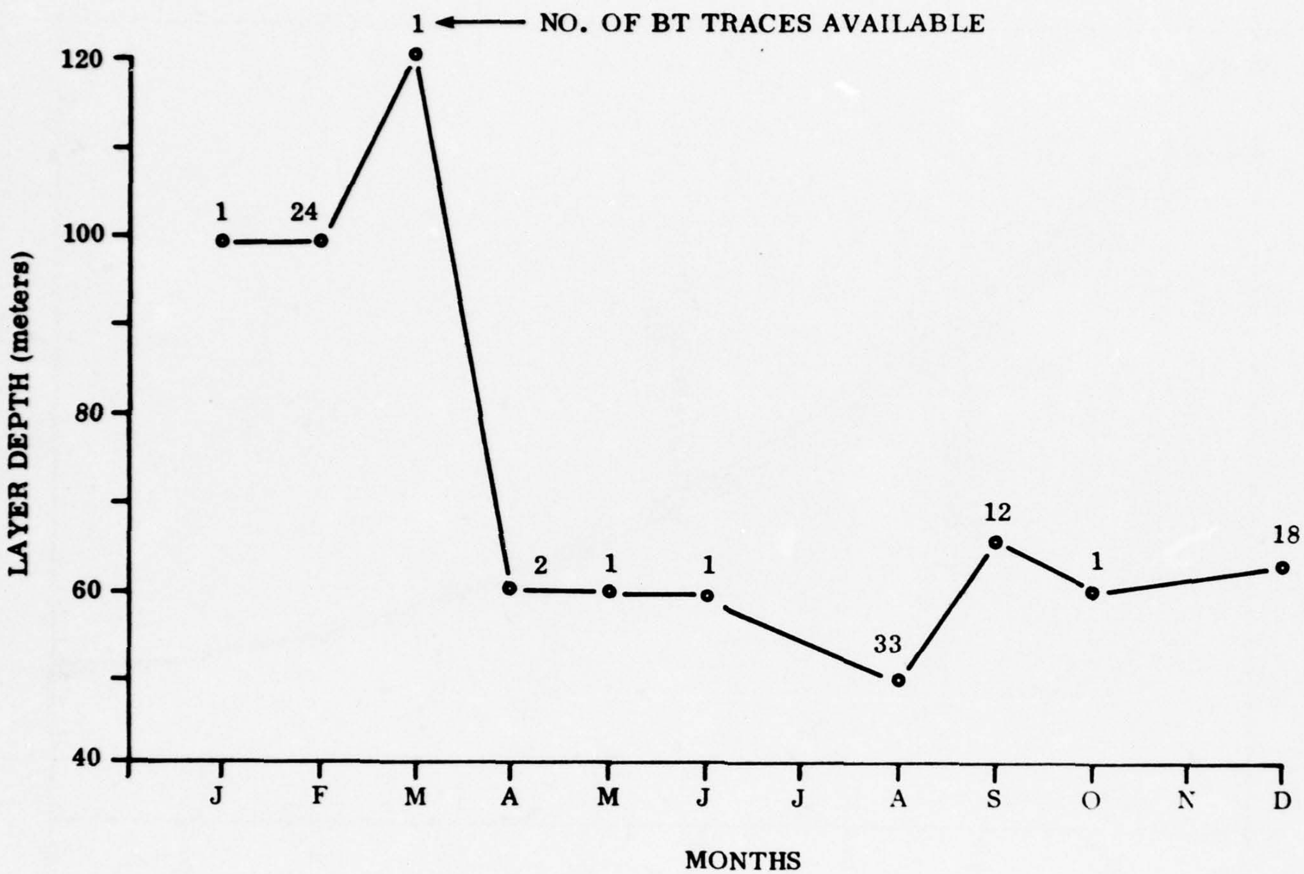


FIGURE 52 MONTHLY VARIATION OF LAYER DEPTH

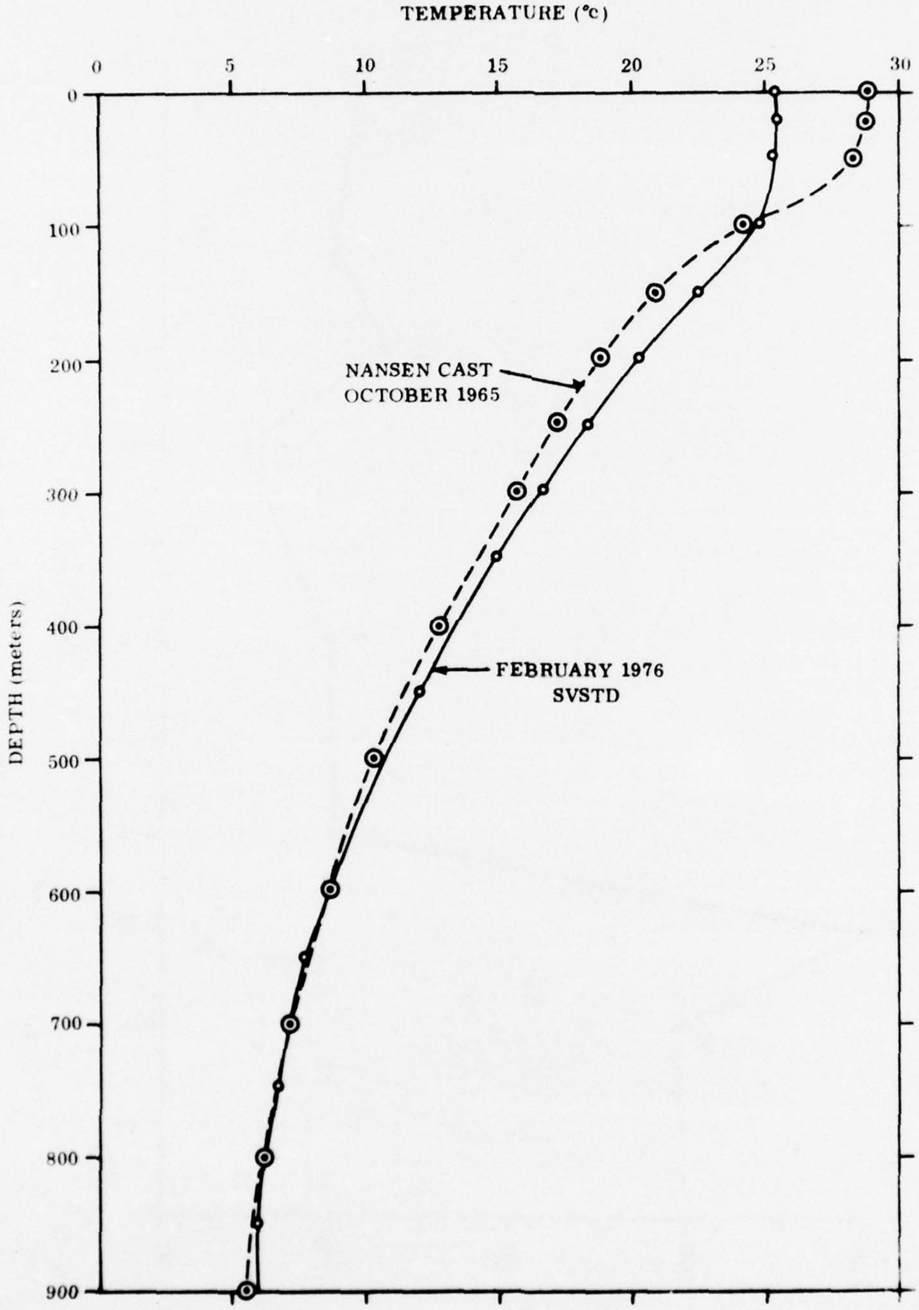


FIGURE 53 TYPICAL TEMPERATURE PROFILES, FEBRUARY AND OCTOBER

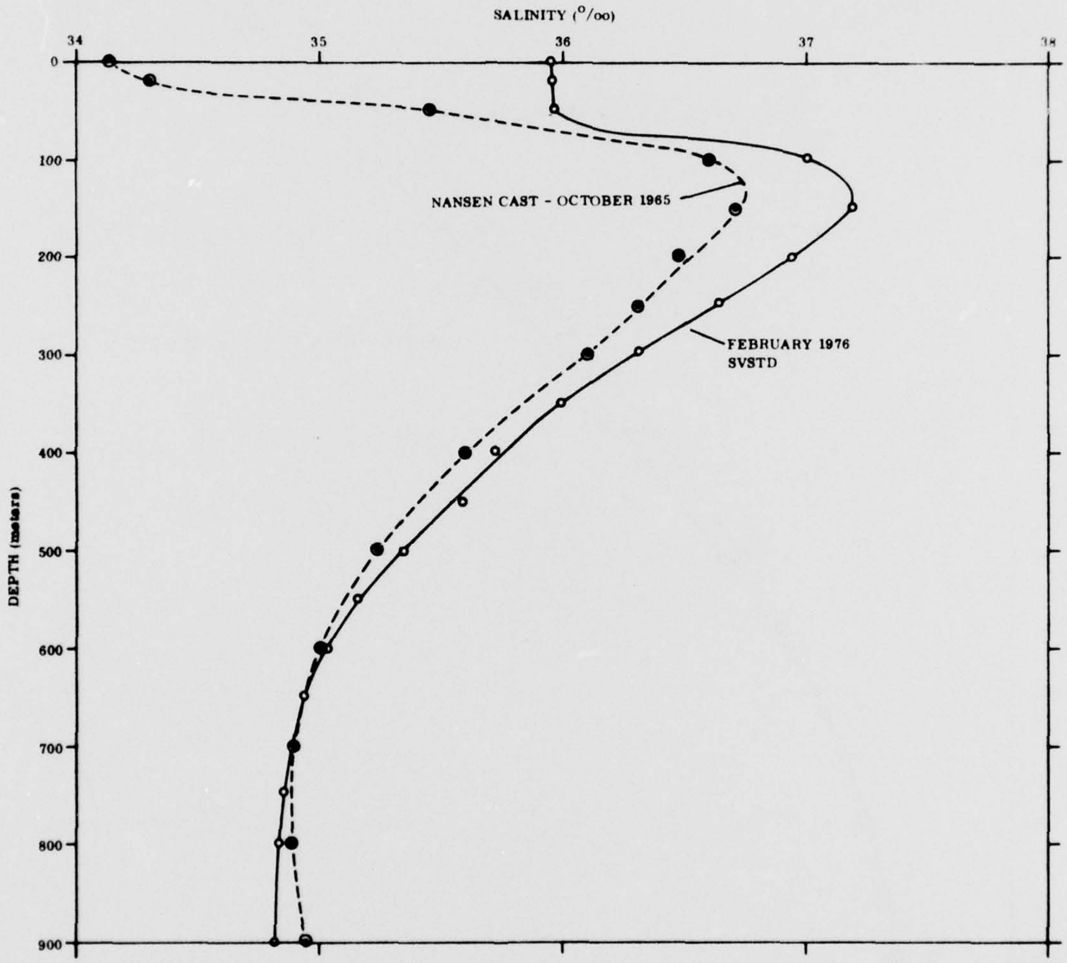


FIGURE 54 TYPICAL SALINITY PROFILES, FEBRUARY AND OCTOBER

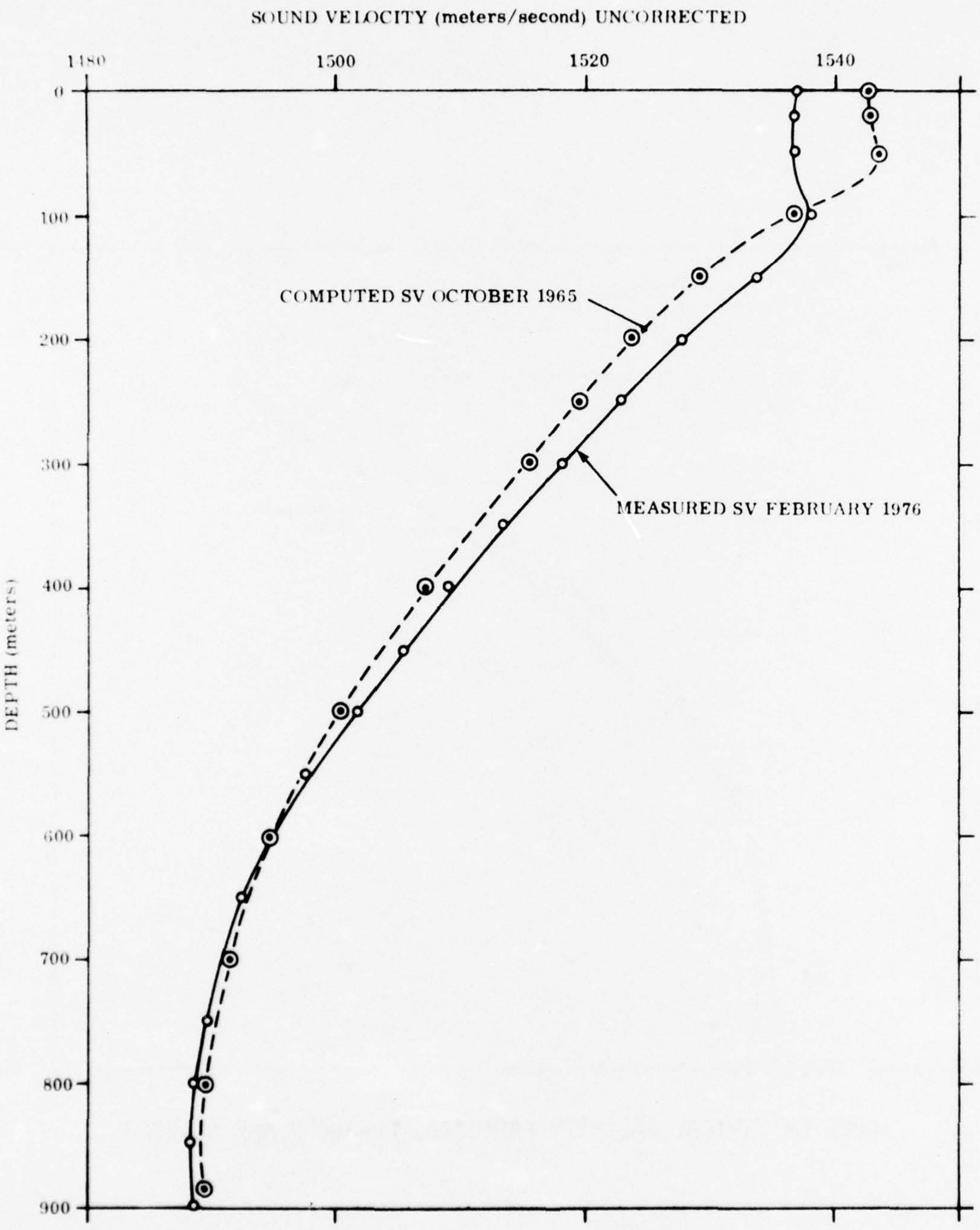


FIGURE 55 TYPICAL SOUND VELOCITY PROFILES, FEBRUARY AND OCTOBER

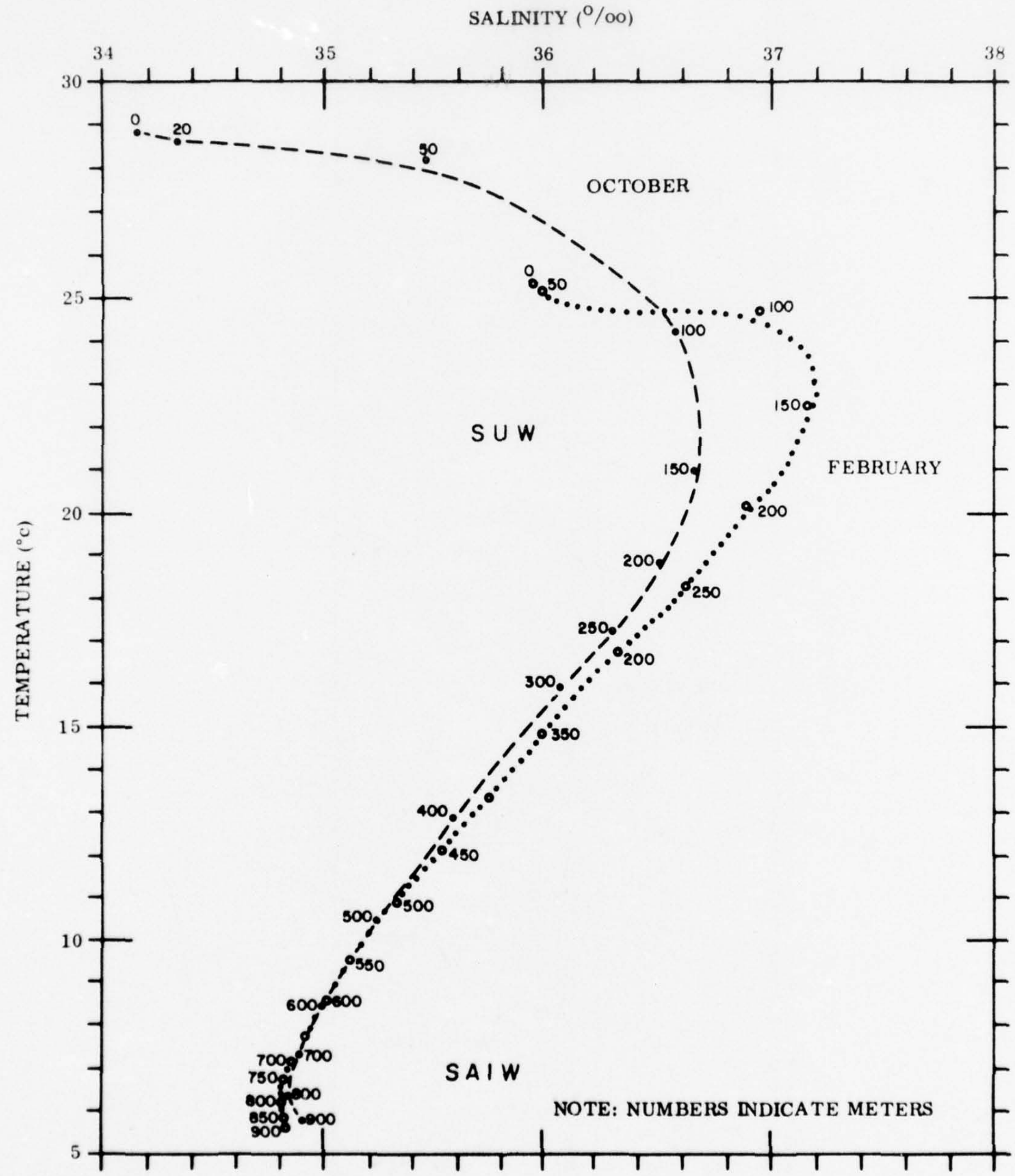


FIGURE 56 T-S DIAGRAMS FOR FEBRUARY AND OCTOBER

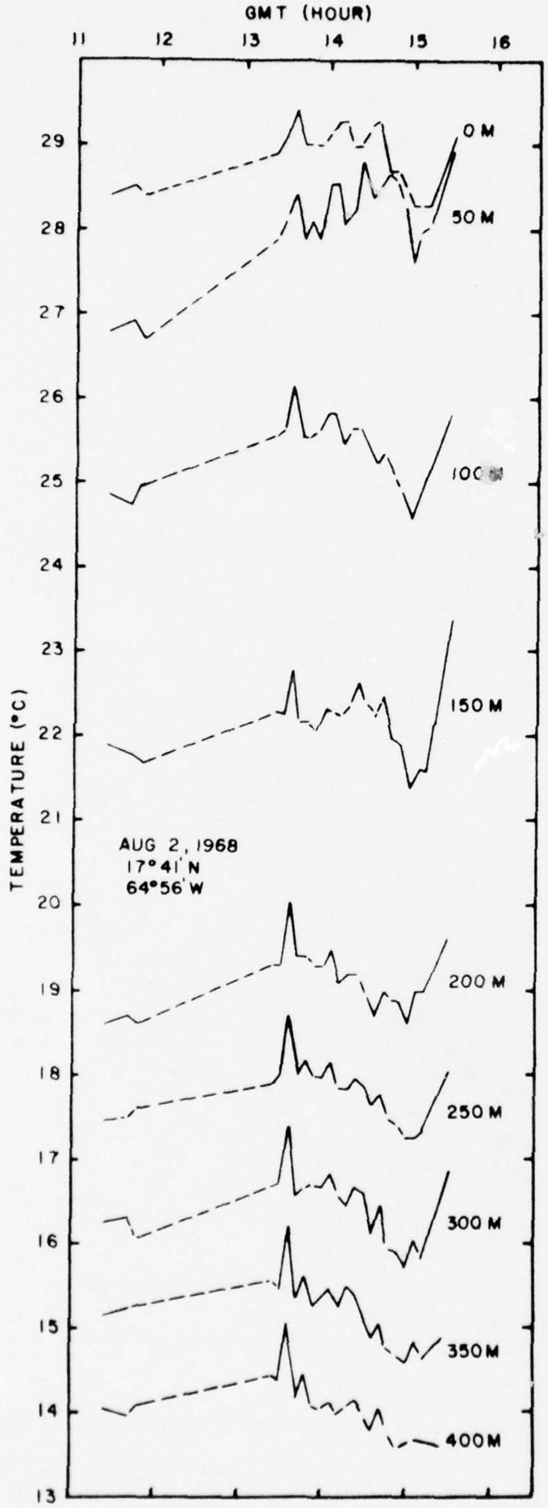


FIGURE 57 TYPICAL TEMPERATURE VARIATIONS DURING AUGUST

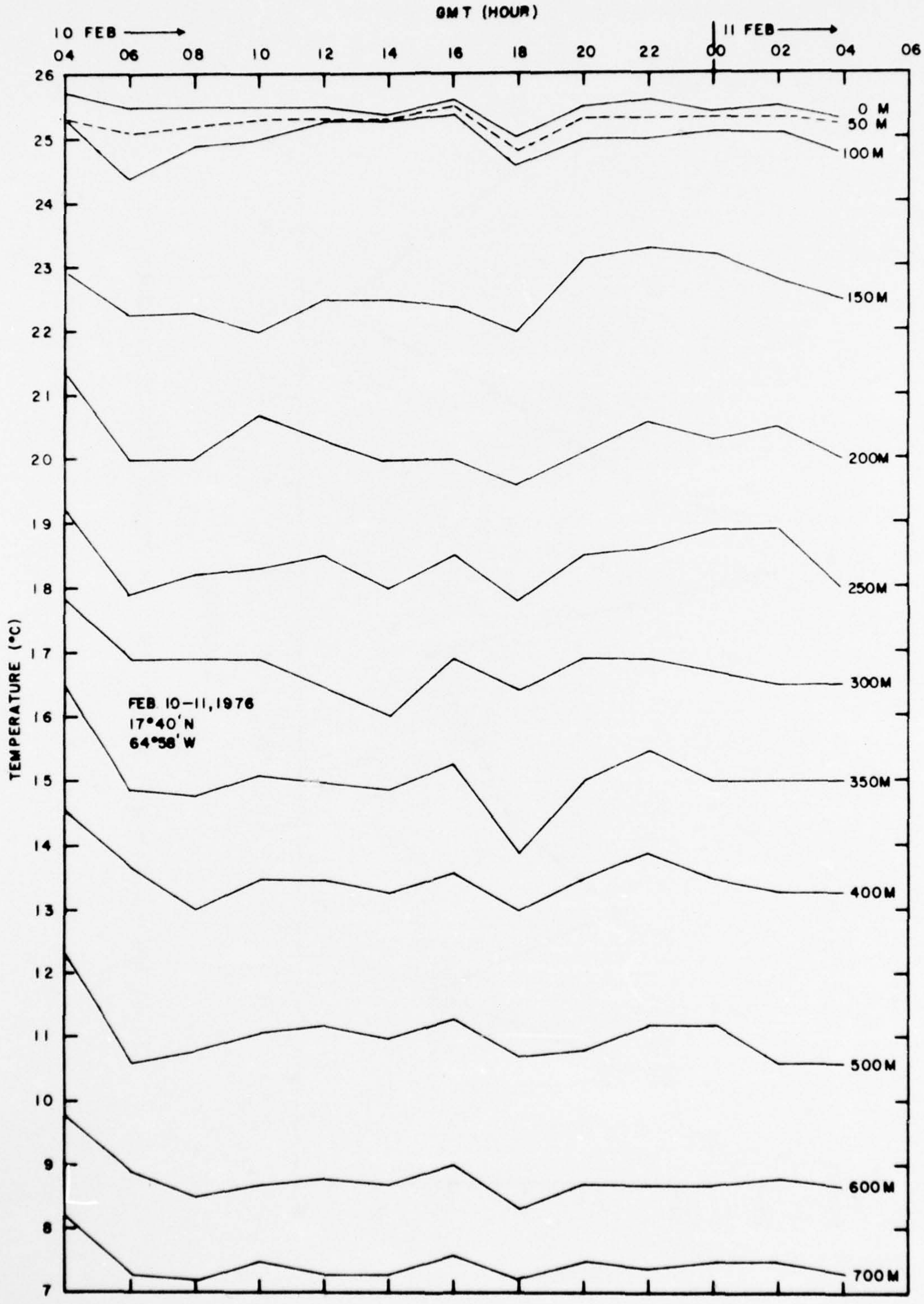


FIGURE 58 TYPICAL TEMPERATURE VARIATIONS DURING FEBRUARY

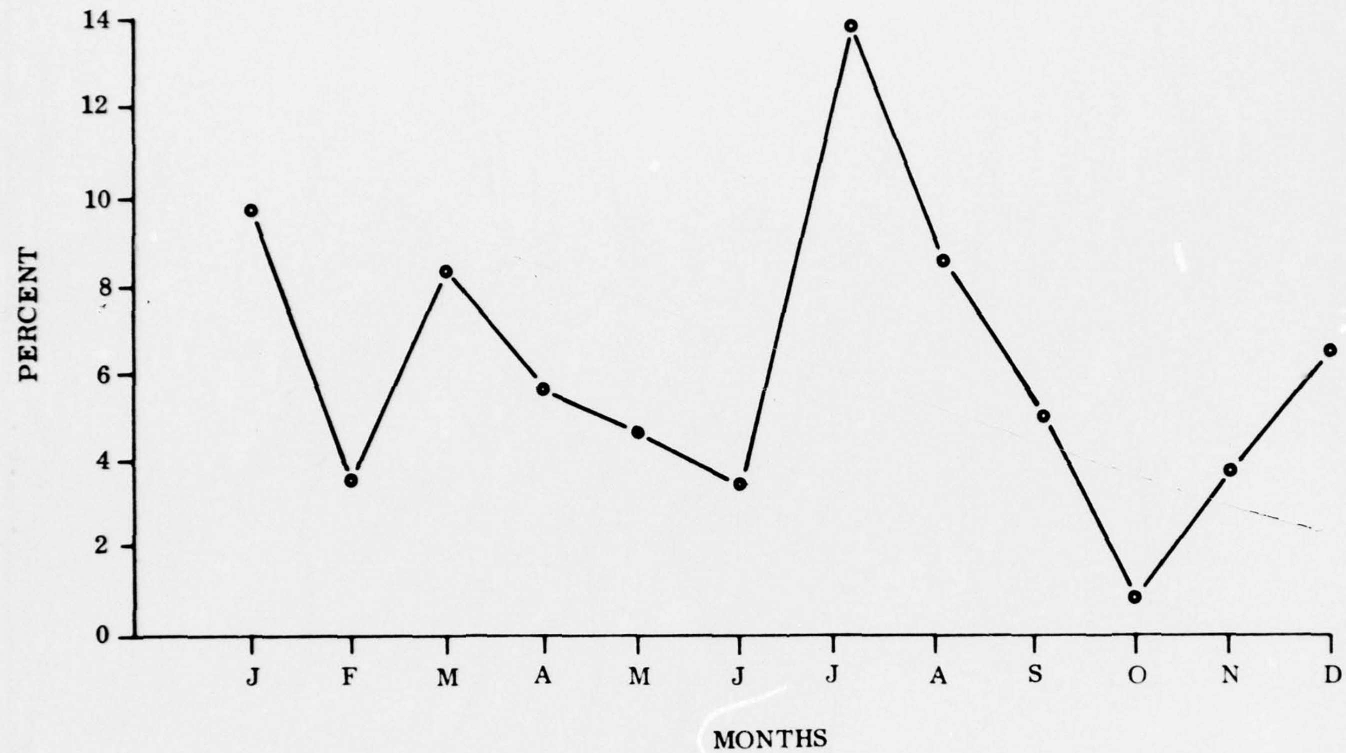


FIGURE 59 MONTHLY WAVE HEIGHT (>6 FT) PROBABILITY DISTRIBUTION

(WAVE DIR. FROM)

WAVE DIR.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
N	7.1	5.5	4.4	4.8	0.9	-	-	0.4	1.8	0.6	6.0	4.3	3.0
NE	36.9	27.1	39.1	29.6	9.3	7.7	16.9	13.3	14.3	12.5	23.7	38.6	22.4
E	50.2	47.3	46.6	45.7	65.9	71.8	70.3	69.8	58.8	62.1	54.9	38.9	56.9
SE	5.8	18.2	6.7	10.4	22.0	19.1	10.4	15.0	17.8	17.3	8.0	10.2	13.4
S	-	1.1	1.4	1.9	1.9	0.7	1.6	0.8	3.5	5.6	3.3	3.8	2.1
SW	-	-	-	0.7	-	-	0.8	-	1.5	0.4	-	0.7	0.3
W	-	-	-	0.5	-	-	-	-	-	-	-	-	—
NW	-	0.8	0.6	3.1	-	-	-	0.1	-	-	1.3	0.7	0.6
VAR	-	-	1.2	3.3	-	0.7	-	0.6	2.3	1.5	2.8	2.8	1.3

PERCENT FREQUENCY

FIGURE 60 MONTHLY SIGNIFICANT WAVE DIRECTION PROBABILITY DISTRIBUTION

(SWELL DIR. FROM)

SWELL DIR.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
N	4.0	12.0	2.0	4.0	-	-	-	1.0	3.0	2.0	4.0	4.0	2.2
NE	43.0	28.0	27.0	26.0	8.0	9.0	22.0	16.0	20.0	12.0	35.0	31.0	23.1
E	38.0	33.0	27.0	39.0	50.0	56.0	53.0	50.0	36.0	50.0	37.0	35.0	42.0
SE	5.0	12.0	14.0	8.0	20.0	22.0	13.0	9.0	15.0	10.0	5.0	7.0	11.7
S	1.0	-	-	1.0	1.0	2.0	-	-	-	3.0	1.0	3.0	1.0
SW	-	1.0	-	-	-	-	-	-	-	-	1.0	-	0.2
W	-	-	-	1.0	-	-	-	-	-	1.0	-	1.0	0.2
NW	2.0	-	3.0	1.0	-	-	-	-	-	1.0	2.0	-	0.8
CALM	7.0	24.0	27.0	20.0	21.0	11.0	12.0	24.0	26.0	21.0	15.0	19.0	18.9

PERCENT FREQUENCY

FIGURE 61 MONTHLY SWELL DIRECTION PROBABILITY DISTRIBUTION

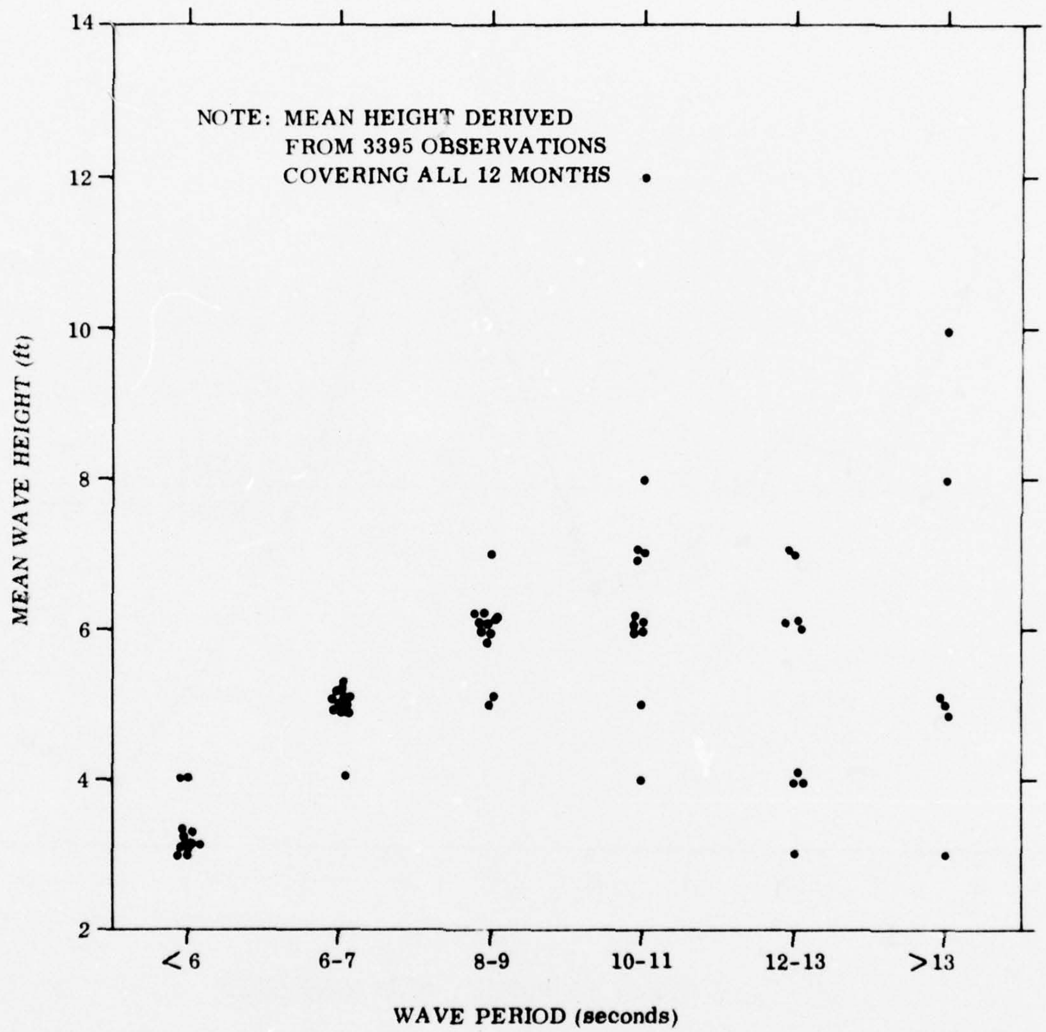


FIGURE 62 WAVE HEIGHT VERSUS WAVE PERIOD

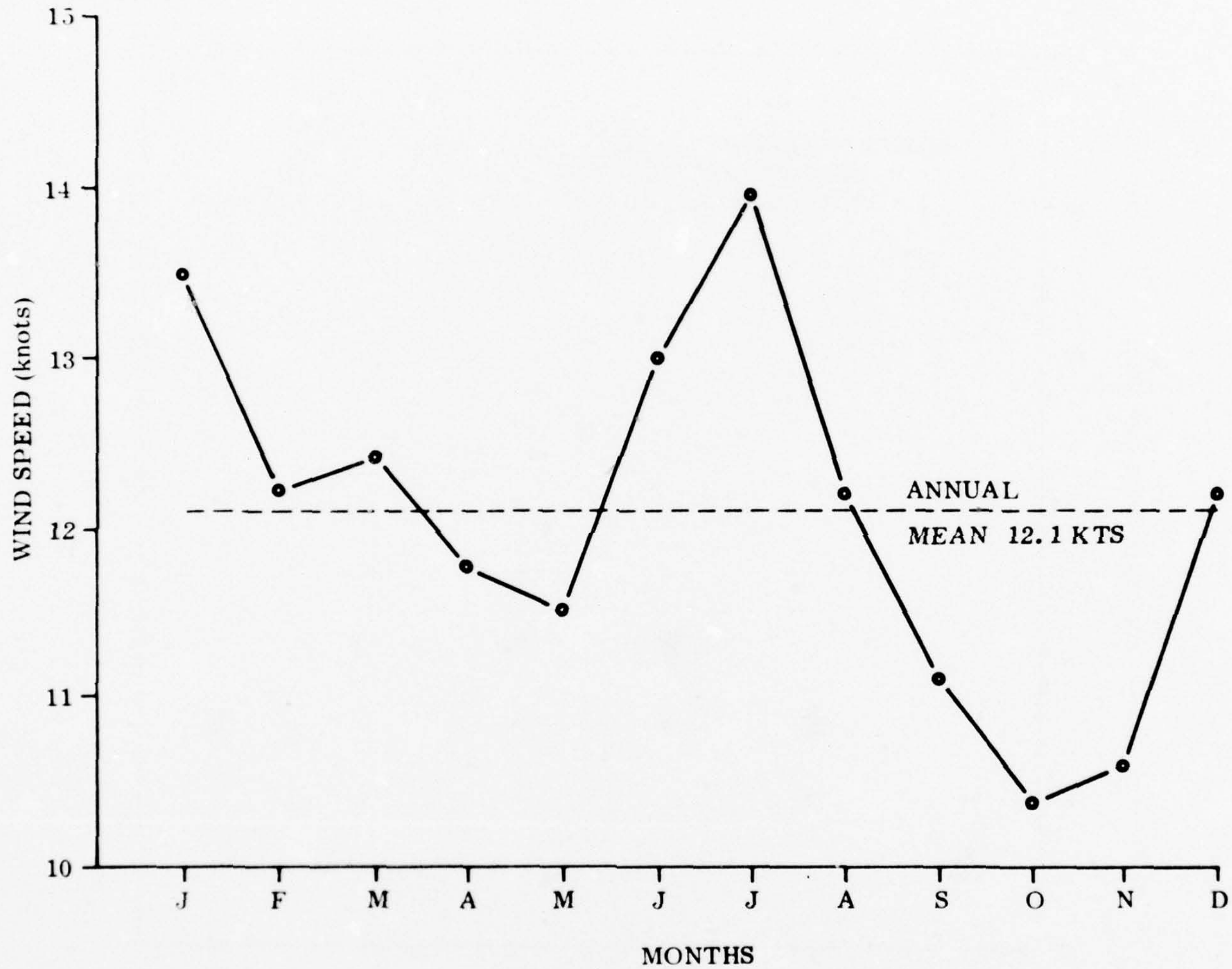


FIGURE 63 MONTHLY MEAN WIND SPEED

WIND DIR.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
N	3.8	3.6	3.4	2.9	0.7	0.3	0.2	0.7	1.3	0.4	3.2	3.4	2.0
NE	39.1	31.1	31.1	22.0	11.5	10.1	17.5	16.7	16.4	14.3	27.0	35.5	22.7
E	48.6	49.2	51.1	53.0	58.4	67.4	69.5	65.6	56.5	55.3	47.2	45.8	55.6
SE	6.5	12.8	11.0	15.9	26.1	20.7	11.7	13.4	20.4	20.8	14.2	10.2	15.3
S	0.3	1.6	1.5	3.4	2.0	1.4	0.7	1.4	3.4	5.2	3.8	2.3	2.2
SW	0.2	0.2	0.2	0.9	0.4	0.0	0.3	0.9	0.9	1.7	1.5	0.4	.6
W	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.0	.2
NW	0.6	0.4	0.5	0.8	0.2	0.0	0.0	0.4	0.3	0.5	0.7	0.6	.4
CALM	0.2	0.7	1.1	1.1	0.8	0.2	0.2	0.7	0.9	1.4	2.0	1.8	0.9

PERCENT FREQUENCY

FIGURE 64 MONTHLY WIND DIRECTION PROBABILITY DISTRIBUTION

WIND DIR.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
N	12.8	10.2	10.7	9.8	8.9	9.0	16.0	12.5	10.0	3.7	8.9	15.0	10.6
NE	14.4	13.1	13.1	13.0	11.7	14.9	14.7	12.6	11.4	10.3	11.0	13.5	12.8
E	13.2	12.7	13.1	12.6	12.3	13.5	14.1	12.6	11.6	11.2	11.8	12.4	12.6
SE	12.6	10.0	9.7	10.4	10.5	10.8	13.4	11.2	10.0	9.8	9.3	9.7	10.6
S	8.3	8.2	8.2	7.1	7.9	10.2	7.1	9.0	13.2	8.5	7.1	8.5	8.6
SW	9.0	9.0	9.0	4.1	4.5	-	11.6	9.8	7.9	8.4	5.0	5.0	6.9
W	15.7	5.0	3.5	5.0	-	-	-	-	9.0	5.0	5.0	-	4.0
NW	9.2	8.9	6.6	8.4	3.0	-	-	9.1	8.4	3.4	8.5	6.1	5.9
Weighted Mean	13.5	12.2	12.4	11.8	11.5	13.0	14.0	12.2	11.1	10.4	10.6	12.2	12.1

KNOTS

No Obs.	467	732	666	552	499	531	461	538	460	489	458	448	6301

FIGURE 65 MONTHLY MEAN WIND SPEED PROBABILITY DISTRIBUTION

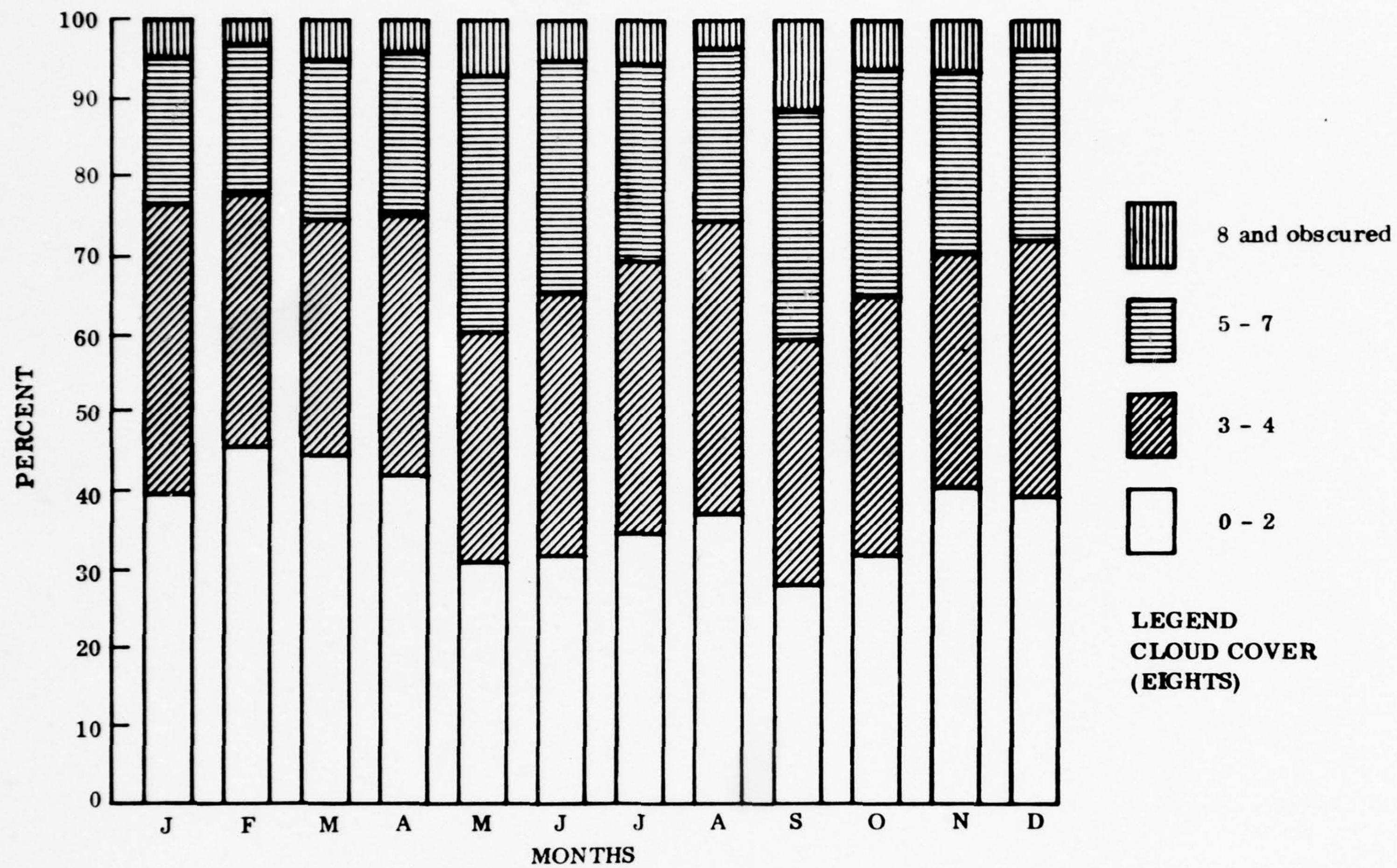


FIGURE 66 PERCENT FREQUENCY OF TOTAL CLOUD COVER (EIGHTS)

APPENDIX A

BIVARIATE DISTRIBUTION OF CURRENT SPEED AND DIRECTION

FEBRUARY 1976

ST CROIX TRACKING RANGE VI ARRAY 1 17 43N 64 55W VCM 264 WD= 777M C =762M START
TIME 0000Z 25 FEB 6976 DT=15 MINS, M VAR APPLIED 10.2W

DIRECTION	0	5	10	15	20	SUM	PER.CT.
0- 15	92	166	32	3		293	4.8
15- 30	96	204	61	8	5	376	6.2
30- 45	99	201	68	28	4	400	6.6
45- 60	97	249	56	10		412	6.8
60- 75	106	160	24	3		293	4.8
75- 90	99	123	17	2		241	4.0
90-105	74	109	2			185	3.0
105-120	74	77	6			157	2.6
120-135	85	59	2	1		147	2.4
135-150	81	64	5	1		151	2.5
150-165	66	66	9	1		142	2.3
165-180	74	84	18			176	2.9
180-195	91	97	15	3		206	3.4
195-210	100	152	29	3		284	4.7
210-225	99	148	70	8		325	5.3
225-240	113	178	108	25	3	427	7.0
240-255	89	177	99	18	1	384	6.3
255-270	109	142	54	2		307	5.0
270-285	93	107	18	1		220	3.6
285-300	77	92	5			174	2.9
300-315	87	66	5			158	2.6
315-330	94	68	4			166	2.7
330-345	77	78	11			167	2.7
345-360	102	111	23			237	3.9

SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
SUM	2174	2980	741	117	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6028
PER.CT.	35.6	48.8	12.1	1.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

NUMBER OF ZERO SPEED AVERAGES = 73 PERCENTAGE ZERO SPEED AVERAGES = 1.2
TOTAL NUMBER OF OBS. = 6101

TABLE A1 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 1 AT 762 METERS

ST CROIX TRACKING RANGE VI ARRAY 1 17 43N 64 55W VCM 291 WD= 777M CM=747M START
TIME 0000Z 25 FEB 6976 DT=15 MINS, M VAR APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	SUM	PER,CT.
0- 15	110	221	44	1																		377	6,2
15- 30	100	185	70	12	1																	368	6,0
30- 45	84	207	73	18	6																	389	6,4
45- 60	94	183	51	8																		336	5,5
60- 75	99	110	25	2																		236	3,9
75- 90	82	87	11																			180	3,0
90-105	85	65																				150	2,5
105-120	83	48	3																			134	2,2
120-135	94	47	3																			144	2,4
135-150	73	66	2																			141	2,3
150-165	89	81	10																			180	3,0
165-180	111	100	12																			223	3,7
180-195	120	117	29	2																		268	4,4
195-210	126	131	36																			293	4,8
210-225	125	142	38	7																		312	5,1
225-240	132	131	29	5																		297	4,9
240-255	118	107	16	2																		243	4,0
255-270	100	93	7																			200	3,3
270-285	86	65	7																			158	2,6
285-300	85	46	1																			132	2,2
300-315	96	38	2																			136	2,2
315-330	67	35	1																			103	1,7
330-345	87	49	3																			139	2,3
345-360	86	119	9																			214	3,5
SUM	2332	2473	482	57	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		5953	
PER,CT.	38,2	40,5	7,9	0,9	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0			

NUMBER OF ZERO SPEED AVERAGES = 748   PERCENTAGE ZERO SPEED AVERAGES = 12,3
TOTAL NUMBER OF OBS, = 6101

TABLE A2 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 1 AT 747 METERS

ST CROIX TRACKING RANGE VI ARRAY 2 17 45N 64 57W VCM 295 WD=1079M CM=1064M START
TIME 0000Z 23 FEB 6976 DT=15 MINS, M VAR APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	30	SUM	PER,CT.
0- 15	100	131	154	152	81	15	1	634	10,3
15- 30	80	77	49	18	5			229	3,7
30- 45	72	46	18	2	2			140	2,3
45- 60	69	38	6	1				114	1,8
60- 75	70	38	6	5	3			122	2,0
75- 90	69	54	19	2				144	2,3
90-105	64	96	16					176	2,9
105-120	87	161	40	2	2	1		293	4,7
120-135	63	172	96	14	1			346	5,6
135-150	78	132	93	35				338	5,5
150-165	77	138	115	43	2			375	6,1
165-180	59	148	127	64	9			407	6,6
180-195	61	91	67	81	20	6		326	5,3
195-210	62	82	35	12	4			195	3,2
210-225	52	35	9					97	1,6
225-240	46	30	2					78	1,3
240-255	33	16	1					50	0,8
255-270	34	6	1					41	0,7
270-285	38	20						58	0,9
285-300	49	20	2					71	1,2
300-315	55	36	5					96	1,6
315-330	68	47	21	2				138	2,2
330-345	81	106	144	73	20			424	6,9
345-360	86	141	221	339	372	97	4	1260	20,4

SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
SUM	1553	1861	1247	845	521	119	5	0	0	0	0	0	0	0	0	0	0	0	0			6152
PER,CT.	25,2	30,1	20.2	13,7	8.4	1,9	0,1	0,0	0,0	0,0	0.0	0,0	0,0	0,0	0.0	0,0	0.0	0,0	0.0	0,0		

NUMBER OF ZERO SPEED AVERAGES = 21 PERCENTAGE ZERO SPEED AVERAGES = 0,3
TOTAL NUMBER OF OBS, = 6173

TABLE A3 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 2 AT 1064 METERS

ST CROIX TRACKING RANGE VI ARRAY 2 17 45N 64 57W VCM 252 WD=1079M CM=1049M START
TIME 0000Z 23 FEB 6976 DT=15 MINS, M VAR APPLIED 10,2M

DIRECTION	0	5	10	15	20	25	30	35	SUM	PER,CT.
0- 15	99	101	79	80	41	9			409	6,6
15- 30	124	99	73	25	4			1	326	5,3
30- 45	124	115	49	20	1				310	5,0
45- 60	123	90	44	10					267	4,3
60- 75	112	86	21	5	2				226	3,7
75- 90	103	80	10						193	3,1
90-105	110	89	2						201	3,3
105-120	119	98	2						219	3,5
120-135	112	126	11		2				251	4,1
135-150	117	184	45	5					351	5,7
150-165	130	208	95	31					464	7,5
165-180	107	183	118	58	9				475	7,7
180-195	100	169	93	52	6	2			424	6,9
195-210	87	94	58	21	2				262	4,2
210-225	101	69	8						178	2,9
225-240	70	36	1						107	1,7
240-255	65	18	1						84	1,4
255-270	67	13							80	1,3
270-285	56	20							76	1,2
285-300	66	34							100	1,6
300-315	66	33	3						102	1,7
315-330	77	51	33	1					162	2,6
330-345	63	92	73	42	17	5	2		314	5,1
345-360	94	96	73	130	135	31	2		561	9,1

SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
SUM	2212	2164	892	480	221	47	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6142
PER,CT.	37,5	35,4	14,5	7,8	3,6	0,8	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	

NUMBER OF ZERO SPEED AVERAGES = 31 PERCENTAGE ZERO SPEED AVERAGES = 0,5
TOTAL NUMBER OF OBS, = 6173

TABLE A4 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 2 AT 1049 METERS

ST CROIX TRACKING RANGE VI ARRAY 2 17 45N 64 57W VCM 253 WD=1079M CM=1018M START
TIME 0000Z 23 FEB 6976 DT=15 MINS, M VAR APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	SUM	PER,CT.
0- 15	109	74	43	27	12		265	4,3
15- 30	101	94	34	30	2		261	4,2
30- 45	131	145	34	14	4		328	5,3
45- 60	164	200	58	20	1		443	7,2
60- 75	174	183	42	11	3	1	414	6,7
75- 90	149	170	13	3			335	5,4
90-105	150	117	15				282	4,6
105-120	116	108	6				230	3,7
120-135	145	107	3				255	4,1
135-150	134	167	15				316	5,1
150-165	149	212	38	1			400	6,5
165-180	154	241	101	17			513	8,3
180-195	126	218	98	50	12		504	8,2
195-210	95	146	55	20	2		318	5,2
210-225	93	95	16	4			208	3,4
225-240	90	46	1	1			138	2,2
240-255	75	27	1				103	1,7
255-270	73	16					89	1,4
270-285	66	15					81	1,3
285-300	69	21	2				92	1,5
300-315	68	26	4				98	1,6
315-330	80	38	5				123	2,0
330-345	86	58	19	1	1		165	2,7
345-360	61	58	30	19	14	6	188	3,0

SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
SUM	2658	2582	633	218	51	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6149
PER,CT.	43,1	41,8	10,3	3,5	0,8	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	

NUMBER OF ZERO SPEED AVERAGES = 24 PERCENTAGE ZERO SPEED AVERAGES = 0,4
TOTAL NUMBER OF OBS. = 6173

TABLE A5 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 2 AT 1018 METERS

ST CROIX TRACKING RANGE VI ARRAY 3 17 43N 64 59W VCM 290 WD= 978M CM=963M START
TIME 0000Z 25 FEB 1976 DT=15 MINS, H VAR APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	SUM	PER.CT.
0- 15	102	175	70	12	1																	360	5,9
15- 30	99	196	129	26	5	2																457	7,4
30- 45	92	199	161	43	1																	496	8,1
45- 60	97	152	80	18	1																	348	5,7
60- 75	66	131	51	7																		255	4,2
75- 90	52	93	28	8	1																	182	3,0
90-105	64	48	19	1																		132	2,2
105-120	51	40	8																			99	1,6
120-135	31	41	4																			76	1,2
135-150	33	26	5																			64	1,0
150-165	53	20	7																			80	1,3
165-180	53	30	4																			87	1,4
180-195	60	43	10																			113	1,8
195-210	66	87	13																			166	2,7
210-225	77	113	51	10																		251	4,1
225-240	67	154	81	22																		324	5,3
240-255	71	175	92	27	15	4	1															385	6,3
255-270	64	198	108	32	5	6	2															415	6,8
270-285	88	159	54	15	5																	321	5,2
285-300	94	151	37	13																		295	4,8
300-315	100	165	23	3																		291	4,7
315-330	97	139	23																			259	4,2
330-345	106	155	41	5																		307	5,0
345-360	87	149	47	14	1																	298	4,9
SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100		
SUM	1770	2839	1146	256	35	12	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6061	
PER.CT.	28,8	46,3	18,7	4,2	0,6	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		

NUMBER OF ZERO SPEED AVERAGES = 76 PERCENTAGE ZERO SPEED AVERAGES = 1.2
TOTAL NUMBER OF OBS. = 6137

TABLE A6 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 3 AT 963 METERS

ST CROIX TRACKING RANGE VI ARRAY 3 17 43N 64 59W VCM 294 WD= 978M CM=948M START
TIME 0000Z 25 FEB 6976 DT=15 MINS, M VAP APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	SUM	PER,CT.
0- 15	146	142	27																			315	5,1
15- 30	122	233	90	13	3																	461	7,5
30- 45	122	243	129	27																		521	8,5
45- 60	115	211	107	26																		459	7,5
60- 75	119	153	81	8																		361	5,9
75- 90	88	116	34																			238	3,9
90-105	84	81	14																			179	2,9
105-120	91	33	1																			125	2,0
120-135	64	19																				83	1,4
135-150	62	22																				84	1,4
150-165	77	34	5																			116	1,9
165-180	68	34	7																			109	1,8
180-195	75	54	4																			133	2,2
195-210	85	83	23	1																		192	3,1
210-225	114	135	37	6	1																	293	4,8
225-240	110	179	79	12	2																	382	6,2
240-255	112	148	58	14	6	2																340	5,5
255-270	107	137	30	20	11	4	1															310	5,1
270-285	92	91	15	7																		205	3,3
285-300	88	94	28	4																		214	3,5
300-315	102	71	5	2																		180	2,9
315-330	106	90	7																			203	3,3
330-345	100	100	2	1																		203	3,3
345-360	117	134	17	1																		269	4,4
SUM	2366	2637	800	142	23	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0		5075	
PER,CT.	38,6	43,0	13,0	2,3	0,4	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0			

NUMBER OF ZERO SPEED AVERAGES = 162 PERCENTAGE ZERO SPEED AVERAGES = 2,6
TOTAL NUMBER OF OBS, = 6137

TABLE A7 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 3 AT 948 METERS

ST CROIX TRACKING RANGE VI ARRAY 3 17 43N 64 59W VCM 293 WD= 978M CM=917M START
TIME 0000Z 25 FEB 6976 DT=15 MINS, M VAR APPLIED 10,2W

DIRECTION	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	SUM	PER,CT.
0- 15	121	163	9																			293	4,8
15- 30	139	200	32	4																		371	6,0
30- 45	123	240	114	18																		495	8,1
45- 60	144	266	118	14																		542	8,8
60- 75	136	222	58	2																		418	6,8
75- 90	135	163	31																			329	5,4
90-105	108	104	7																			219	3,6
105-120	80	42	7																			129	2,1
120-135	82	44	2																			128	2,1
135-150	79	47	1																			127	2,1
150-165	85	45																				130	2,1
165-180	90	75	10																			175	2,9
180-195	76	72	11																			159	2,6
195-210	112	105	12	2																		231	3,8
210-225	88	153	57	4																		302	4,9
225-240	114	171	48	3																		336	5,5
240-255	126	124	51	9																		310	5,1
255-270	89	140	39	4																		272	4,4
270-285	94	109	20	2																		225	3,7
285-300	85	89	13																			187	3,0
300-315	98	67	2																			167	2,7
315-330	92	61																				153	2,5
330-345	116	74																				190	3,1
345-360	110	132																				242	3,9
SUM	2518	2908	642	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6130	
PER,CT.	41,0	47,4	10,5	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		

NUMBER OF ZERO SPEED AVERAGES = 7 PERCENTAGE ZERO SPEED AVERAGES = 0,1
TOTAL NUMBER OF OBS. = 6137

TABLE A8 BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR ARRAY 3 AT 917 METERS

APPENDIX B

BIVARIATE DISTRIBUTION OF CURRENT SPEED AND DIRECTION
OCTOBER 1965

TABLE B1

Summary of Mooring Locations and Instrument Performance (1965)

Station No.	Location	Water Depth (meters)	Meter Depth (meters)	Record Length	Remarks
5	17°41.6'N	929	145	10/2 - 10/15/65	
	64°57.4'W		815	"	No direction.
			915	"	
			920	"	
6A*	17°43.3'N	929	41	10/3 - 10/4/65	No data.
	64°57.5'W		130	"	
			313	"	
			800	"	
			915	"	No data.
			920	"	No data.
6B	17°43.3'N 64°57.5'W	925	27	10/9 - 10/16/65	No direction first 80 hrs. Beginning and end times doubtful.
			116		
			300		
			786		Meters not recovered.
			910		
			915		
8	17°44.8'N	1064	1050	10/2 - 10/4/65	Continuous recording.
	64°57.1'W		1055	"	No data.
9	17°45.8'N	976	88	10/1 - 10/13/65	
	64°58.3'W		760	"	No direction for first 130 hours.
10	17°44.7'N	976	962	10/1 - 10/13/65	
	64°59.0'W		967	"	

*Moor released prematurely.

STATION NO. 5

Meter Depth -- 145 meters   Water Depth -- 939 meters

	Knots								
	0.05	0.15	0.25	0.35	0.45	0.55	0.65	Total	Percent
NE	10	44	52	60	1	0	0	167	9
E	3	2	0	0	0	0	0	5	0
SE	1	0	3	0	0	0	0	4	0
S	0	2	6	0	0	0	0	8	0
SW	25	55	33	5	3	0	0	121	7
W	45	164	100	7	0	0	0	316	17
NW	45	203	220	28	9	0	0	505	27
N	30	187	250	221	34	11	1	734	39
Total	159	657	664	321	47	11	1		
Pct.	9	35	36	17	3	1	0		

Mean Speed = 0.225 kn.
Resultant Flow = 0.17 kn., 340°

STATION NO. 5

Meter Depth -- 815 meters   Water Depth -- 929 meters

	Knots					
	0.05	0.15	0.25	0.35	0.45	0.55
Total	1562	288	2	0	1	0
Pct.	84	16	0	0	0	0

Mean Speed = 0.055 kn.

TABLE B2. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 5 AT 145 METERS, AND MEAN SPEED FOR STATION NO. 5 AT 815 METERS

STATION NO. 5

Meter Depth -- 915 meters   Water Depth -- 929 meters

	0.05	0.15	Knots 0.25	0.35	0.45	Total	Percent
NE	127	2	0	0	0	129	7
E	225	85	21	2	0	333	19
SE	248	117	24	2	0	391	22
S	121	9	0	0	0	130	7
SW	51	1	0	0	0	52	3
W	111	17	3	0	0	131	7
NW	305	153	23	0	0	481	27
N	115	23	1	0	0	139	8
Total	1303	407	72	4	0		
Pct.	73	23	4	0	0		

Mean Speed = 0.073 kn.
Resultant Flow = 0.02 kn., 065°

STATION NO. 5

Meter Depth -- 920 meters   Water Depth -- 929 meters

	0.05	0.15	0.25	0.35	0.45	0.55	Total	Percent
NE	122	16	0	0	0	0	138	7
E	228	133	32	10	1	0	404	22
SE	247	125	44	3	1	0	420	23
S	81	8	0	1	0	0	90	5
SW	40	1	0	0	0	0	41	2
W	84	33	3	0	0	0	120	6
NW	232	192	38	4	0	0	466	25
N	130	28	10	0	0	0	168	9
Total	1164	536	127	18	2	0		
Pct.	63	29	7	1	0	0		

Mean Speed = 0.087 kn.
Resultant Flow = 0.01 kn., 050°

TABLE B3. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 5 AT 920 AND 915 METERS

STATION NO. 6A

Meter Depth -- 130 meters   Water Depth -- 929 meters

	Knots						
	0.05	0.15	0.25	0.35	0.45	Total	Percent
NE	12	6	3	0	0	21	10
E	0	3	0	0	0	3	1
SE	4	0	0	0	0	4	2
S	13	29	4	0	0	46	22
SW	15	4	0	0	0	19	9
W	4	0	0	0	0	4	2
NW	10	11	0	0	0	21	10
N	23	35	22	7	2	89	43
Total	81	88	29	7	2		
Pct.	39	43	14	3	1		

Mean Speed = 0.142 kn.
Resultant Flow = 0.05 kn., 010°

STATION NO. 6A

Meter Depth -- 313 meters   Water Depth -- 929 meters

	Knots					
	0.05	0.15	0.25	0.35	Total	Percent
NE	21	4	0	0	25	11
E	4	2	0	0	6	3
SE	9	14	0	0	23	10
S	12	28	1	0	41	18
SW	33	9	2	0	44	19
W	15	4	0	0	19	8
NW	18	6	0	0	24	10
N	30	19	0	0	49	21
Total	142	86	3	0		
Pct.	61	37	1	0		

Mean Speed = 0.93 kn.
Resultant Flow = .03 kn., 200°

TABLE B4. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 6A AT 313 AND 130 METERS

STATION 6A

Meter Depth -- 800 meters   Water Depth -- 929 meters

	Knots 0.05	0.15	0.25	Total	Percent
NE	29	4	0	33	14
E	37	6	0	43	18
SE	53	25	0	78	33
S	25	9	1	35	15
SW	9	26	0	35	15
W	8	3	0	11	5
NW	0	0	0	0	0
N	5	0	0	5	2
Total	166	73	1		
Pct.	69	30	0		

Mean Speed = 0.085 kn.
Resultant Flow = 0.05 kn., 150°

STATION 6B

Meter Depth -- 27 meters   Water Depth -- 925 meters

	Knots 0.10	0.20	0.30	0.40	0.50	0.60	Total	Percent
NE	2	9	11	0	0	0	22	8
E	8	2	0	0	0	0	10	4
SE	8	4	0	0	0	0	12	5
S	5	7	0	0	0	0	12	5
SW	28	18	7	0	0	0	53	20
W	15	12	0	0	0	0	27	10
NW	8	27	20	2	0	0	57	22
N	6	6	21	27	2	4	66	25

Mean Speed = 0.221 kn.
Resultant Flow = 0.12 kn., 330°

TABLE B5. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 6A AT 800 METERS, AND STATION NO. 6B AT 27 METERS

STATION NO. 8

Meter Depth -- 1050 meters Water Depth -- 1064 meters

	Knots					
	0.05	0.15	0.25	0.35	Total	Percent
NE	649	540	15	0	1204	40
E	262	92	2	0	356	12
SE	239	11	0	0	250	8
S	340	23	0	0	363	12
SW	336	190	3	0	529	18
W	82	27	1	0	110	4
NW	43	9	0	0	52	2
N	110	24	0	0	134	5
Total	2061	916	21	0		
Pct.	69	31	1	0		

Mean Speed = 0.072 kn.
Resultant Flow = 0.03 kn., 055°

STATION NO. 9

Meter Depth -- 88 meters Water Depth -- 976 meters

	Knots									
	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	Total	Percent
NE	7	40	4	2	1	0	0	0	54	3
E	2	8	0	0	0	0	0	0	10	1
SE	13	24	1	0	0	0	0	0	38	2
S	10	40	13	4	0	0	0	0	67	4
SW	17	70	70	46	16	4	6	0	229	13
W	30	116	60	54	42	6	0	0	308	18
NW	21	216	120	50	22	0	0	0	429	25
N	16	110	170	144	96	2	28	3	569	33
Total	116	624	438	300	177	12	34	3		
Pct.	4	37	26	18	10	1	2	0		

Mean Speed = 0.254 kn.
Resultant Flow = 0.15 kn., 320°

TABLE B6. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 8 AT 1050 METERS, AND STATION NO. 9 AT 88 METERS

STATION NO. 9

Meter Depth -- 760 meters   Water Depth -- 976 meters

*	Knots 0.10	0.20	Total	Percent
NE	30	0	30	3
E	17	0	17	2
SE	19	0	19	2
S	131	0	131	14
SW	106	2	108	12
W	48	0	48	5
NW	25	0	25	3
N	23	0	23	3
Total	399	2		
Pct.	44	0		

Mean Speed = 0.046 kn.
Resultant Flow = 0.01 kn., 180°

*Note class intervals centered at 0.10 are bounded by 0.5 and 0.14 knot. There were 503 values less than 0.05 kn. This is a 55.6 percent of total.

STATION NO. 9

Meter Depth -- 962 meters   Water Depth -- 976 meters

	Knot 0.05	0.15	0.25	0.35	0.45	0.55	Total	Percent
NE	111	38	17	5	4	0	175	1
E	124	42	6	2	0	0	175	11
SE	151	60	25	0	0	0	236	14
S	204	132	22	0	0	0	358	22
SW	182	75	6	6	5	0	275	17
W	133	38	3	1	0	0	175	11
NW	84	34	4	0	0	0	122	7
N	89	28	14	3	0	0	134	8
Total	1078	447	97	11	9	0		
Pct.	65	27	6	1	1	0		

Mean Speed = 0.087 kn.
Resultant Flow = 0.02 kn., 180°

TABLE B7. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 9 AT 962 AND 760 METERS

STATION NO. 9

Meter Depth -- 967 meters   Water Depth -- 976 meters

	Knots							
	0.05	0.15	0.25	0.35	0.45	0.55	Total	Percent
NE	97	58	23	13	4	0	195	12
E	144	22	8	7	1	0	182	11
SE	316	221	29	0	0	0	566	34
S	265	143	20	0	0	0	428	25
SW	134	11	0	1	0	0	146	9
W	49	4	0	0	0	0	53	3
NW	35	0	0	0	0	0	35	2
N	66	12	0	0	0	0	78	5
Total	1106	471	80	21	5	0		
Pct.	66	28	5	1	0	0		

Mean Speed = 0.081 kn.
Resultant Flow = 0.05 kn., 135°

STATION NO. 10

Meter Depth -- 962 meters   Water Depth -- 976 meters

	Knots					
	0.05	0.15	0.25	0.35	Total	Percent
NE	139	77	13	0	229	14
E	122	5	1	0	128	8
SE	40	0	0	0	40	3
S	106	19	0	0	125	8
SW	161	135	66	15	377	24
W	164	134	75	26	399	25
NW	110	20	0	0	130	8
N	105	50	9	0	164	10
Total	947	440	164	41		
Pct.	59	28	10	3		

Mean Speed = 0.11 kn.
Resultant Flow = 0.04 kn., 265°

TABLE B8. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION 9 AT 967 METERS AND STATION 10 AT 962 METERS

STATION NO. 10

Meter Depth -- 967 meters   Water Depth -- 976 meters

	Knots					
	0.05	0.15	0.25	0.35	Total	Percent
NE	125	74	8	0	207	13
E	112	18	1	0	131	8
SE	76	1	1	0	78	5
S	83	6	1	0	90	6
SW	185	67	16	0	268	17
W	199	165	112	21	497	31
NW	118	37	9	2	166	10
N	111	22	23	0	156	10
Total	1009	390	171	23		
Pct.	63	24	11	1		

Mean Speed = 0.10 kn.
Resultant Flow = 0.05 kn., 280°

TABLE B9. BIVARIATE DISTRIBUTION OF SPEED AND DIRECTION FOR STATION NO. 10 AT 967 METERS

APPENDIX C

CURRENT AND SHEAR PROFILE MEASUREMENTS

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APPENDIX

CURRENT AND SHEAR PROFILE MEASUREMENTS†

I. INTRODUCTION

Beginning in November of 1974 and continuing through February of 1976 the Applied Physics Laboratory of Johns Hopkins University conducted a program of measurements of the current structure on the St. Croix range. Most of these measurements were made using the technique of acoustically tracking slowly sinking untethered floats which, upon reaching a predetermined maximum depth, would release ballast and return to the surface. By differentiating the measured position time series of the floats the ocean current profiles were obtained. Figure 1 shows the tracking data for one of these drops and Figure 2 shows the corresponding current profile.

In all, 64 drops, most to a depth of 400 meters, were made at various locations on the range and at various times of the year. Sometimes two profilers were dropped simultaneously at different locations on the range to determine the horizontal variability of the current profile. For these joint drops spatial separations ranging from 100 meters to 2 kilometers were chosen. There were also several periods where drops were made repeatedly every two hours at a fixed location (near Array 3 center). These time series measurements were made to determine the amount and nature of the temporal variability of the current profile in order to shed some light on which oceanographic processes were responsible for the currents.

Several drops were made using an instrumented profiler which incorporated a Neil Brown CTD system and a two-axis acoustic current meter.[1] The acoustic current meter was used to measure the fine scale structure in the current profile and the CTD data was gathered to determine the ratio of density to velocity gradient ($\propto$ Richardson Number). In addition, CTD casts were made in conjunction with many of the drops of the uninstrumented profilers again to determine Richardson Number profiles.

†This appendix consists of a brief description of the current measurements that have been made at St. Croix by the Applied Physics Laboratory of Johns Hopkins University and its subcontractors. A detailed report on this work is being prepared and will be available by Dec. 1976. Requests for copies of this report or additional information should be directed to David Wenstrand, Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road, Laurel, Md. 20810.

In February and March, 1976 several radar-tracked drogues[2] and a moored current meter string[2] consisting of five Amf Vector Averaging Current meters were deployed to obtain additional information on the variability of the current field in the upper 300 meters.

In all of these measurements the currents were found to be extremely variable in magnitude and direction with magnitudes ranging from 0 to 30 cm/sec. On the average, current speed was 10 to 15 cm/sec with no direction being strongly preferred.

II. CURRENT PROFILE MEASUREMENTS

The current profile shown in Figure 2 is typical of the many such measurements that were made on the St. Croix range. The extent to which the ascending and descending measurements agree is an indication of the accuracy of the measurement ($\approx$ 0.5 cm/sec) and also of actual temporal variability. The latter is especially important for the upper part of the profile since 40 minutes typically elapsed between the beginning and end of a drop.

From Figure 3, where both horizontal components of current are plotted versus depth, it can be seen that both current magnitude and direction vary rapidly and in an unpredictable manner with increasing depth.

Due to the extreme amount of spatial variability observed on the range, it isn't possible to assign one current profile to the whole range area. In fact, as shown in Figure 4, simultaneous current profiles separated by distances as short as 1400 meters show only gross similarity and much beyond this no significant correlation is observed.

This fact, coupled with the significant amount of temporal variability observed in the profile over periods as short as 2-3 hours, makes it practically impossible to obtain a complete characterization of the entire current field on the range. There-

[1] This instrument was developed by Prof. T. Rossby, formerly of Yale University (now at the Univ. of Rhode Island) who performed the measurements made with it at St. Croix.

[2] The drogue work was performed by Dr. G.R. Stegen of Flow Research, Inc., Kent, Washington, and the mooring work was done by R. Walden and co-workers at Woods Hole Oceanographic Institution.

fore the current field must be characterized with statistical parameters such as vertical wavenumber spectra and correlation lengths and times for profiles separated in space and time, respectively.

Although a quantitative statistical description of the current variability has not been completed, it is apparent from a visual examination of the current profiles gathered at different times of year that no major seasonal variability in these statistical parameters exists.

Similarly, it is in statistical terms that the relationship between current profiles and their corresponding density profiles must be described. Specifically, it appears that the r.m.s. value of the vertical gradient of current (or shear) at one depth is proportional to the average density gradient at that depth. A hint of this can be seen in Figures 5 and 6 which show, respectively, the profile of the east component of velocity and the profiles of temperature, salinity and sound velocity. The most obvious correlation is at the bottom of the mixed layer where the large density gradient seems to be related to a large feature in the current profile. Less obvious is the tendency for the current shear to diminish with depth at about the same rate as the temperature (or density) gradient.

III. CURRENT TIME SERIES MEASUREMENTS

Figure 7 shows a sample 5-day record from one of the current meters on the array implanted by W.H.O.I. on 20 Feb. 1976. Although the array was left in for approximately 2 months, only 1 month of data was actually gathered since the 1 minute sampling rate limited tape life to this period.

Figure 8 shows the trajectory of a drogue which was deployed on the 8th of February, 1976 and tracked by radar for 30 hours. Since the drag member of the drogue was at a depth of 120 meters, this trajectory should be regarded as the trajectory of a parcel of water at that depth.

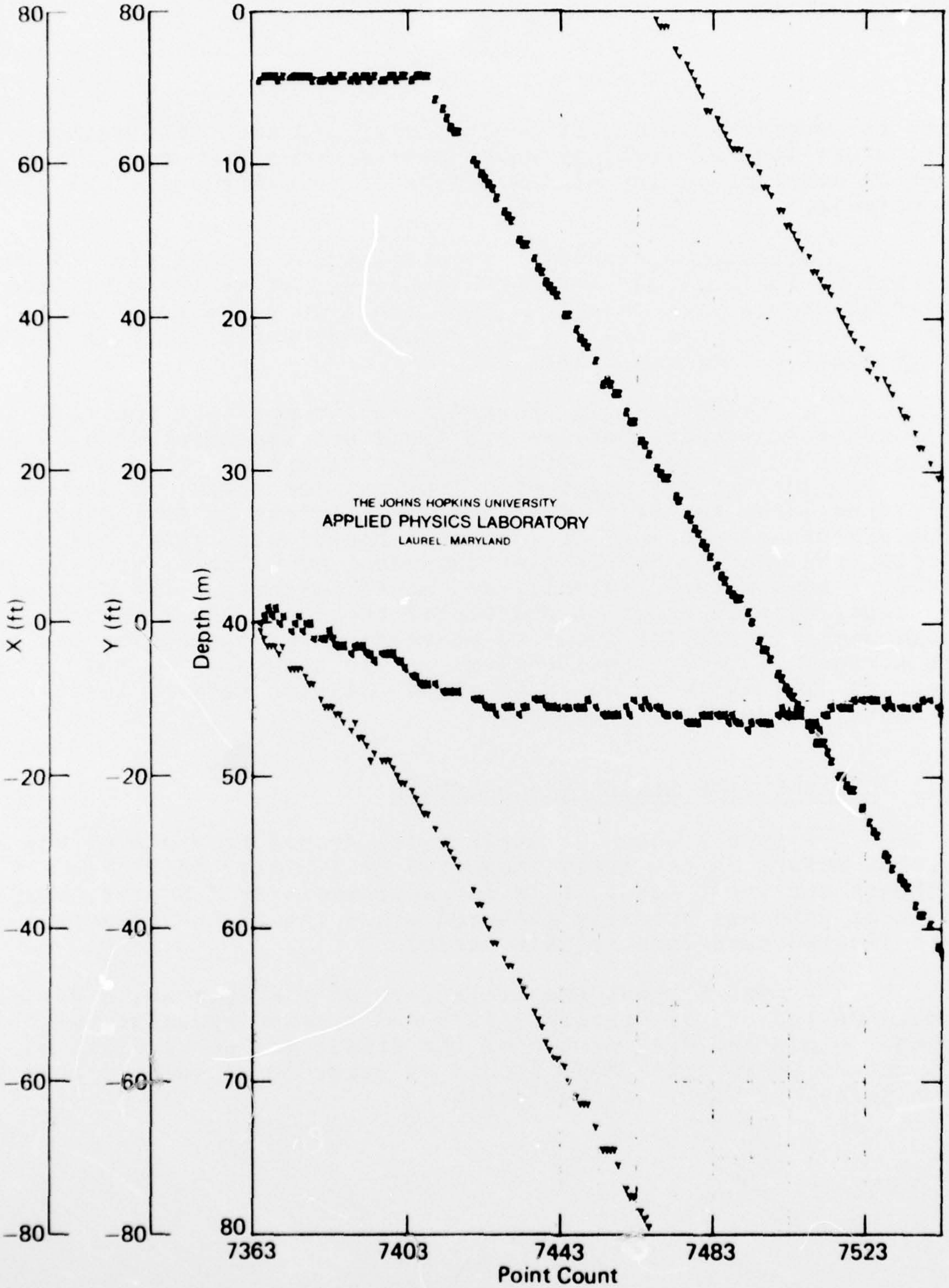

FIGURE C1 **Range Raw Tracking Data for Beginning of Drop 33 in Array 3 (9 Feb 76). The X and Y coordinates are plotted relative to a location occupied by the profiler shortly before release (46806, 32115).**

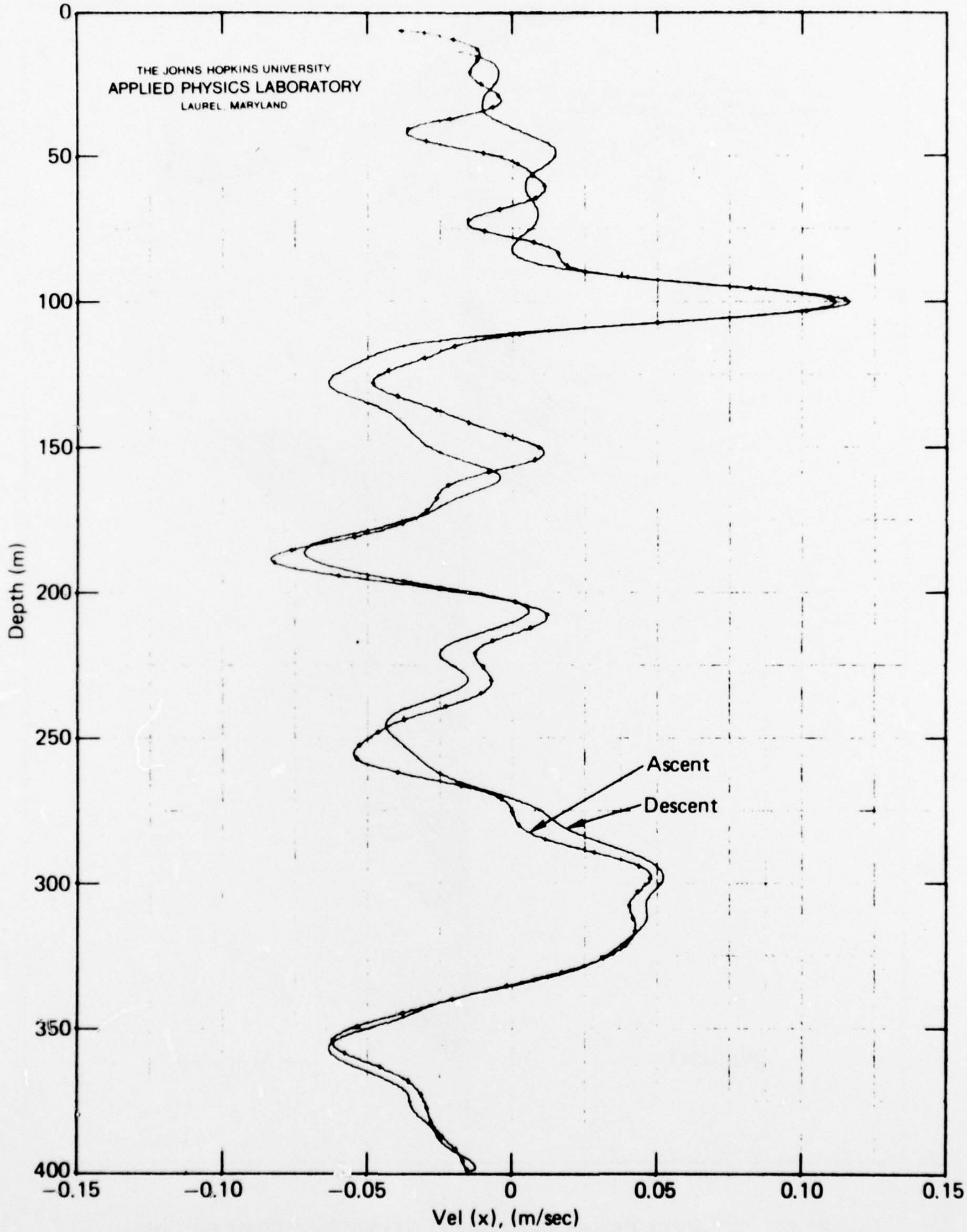

FIGURE C2 **East Component of Current for Drop 33 in Array 3 (9 Feb 76).**

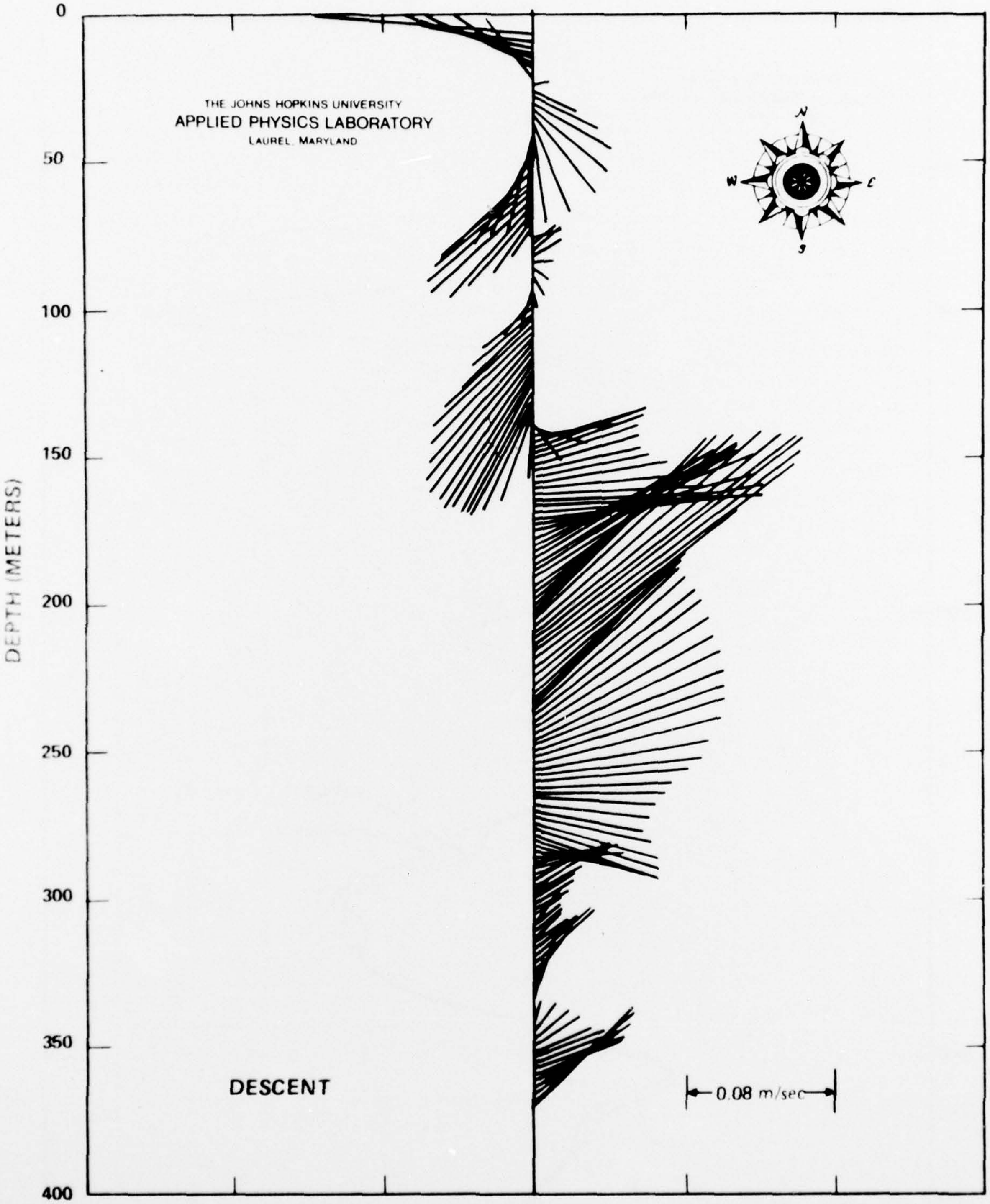

FIGURE C3 **OCEAN CURRENT VECTORS PLOTTED VS. DEPTH FOR APL SHEAR DROP 2 MONDAY – MAY 19, 1975**

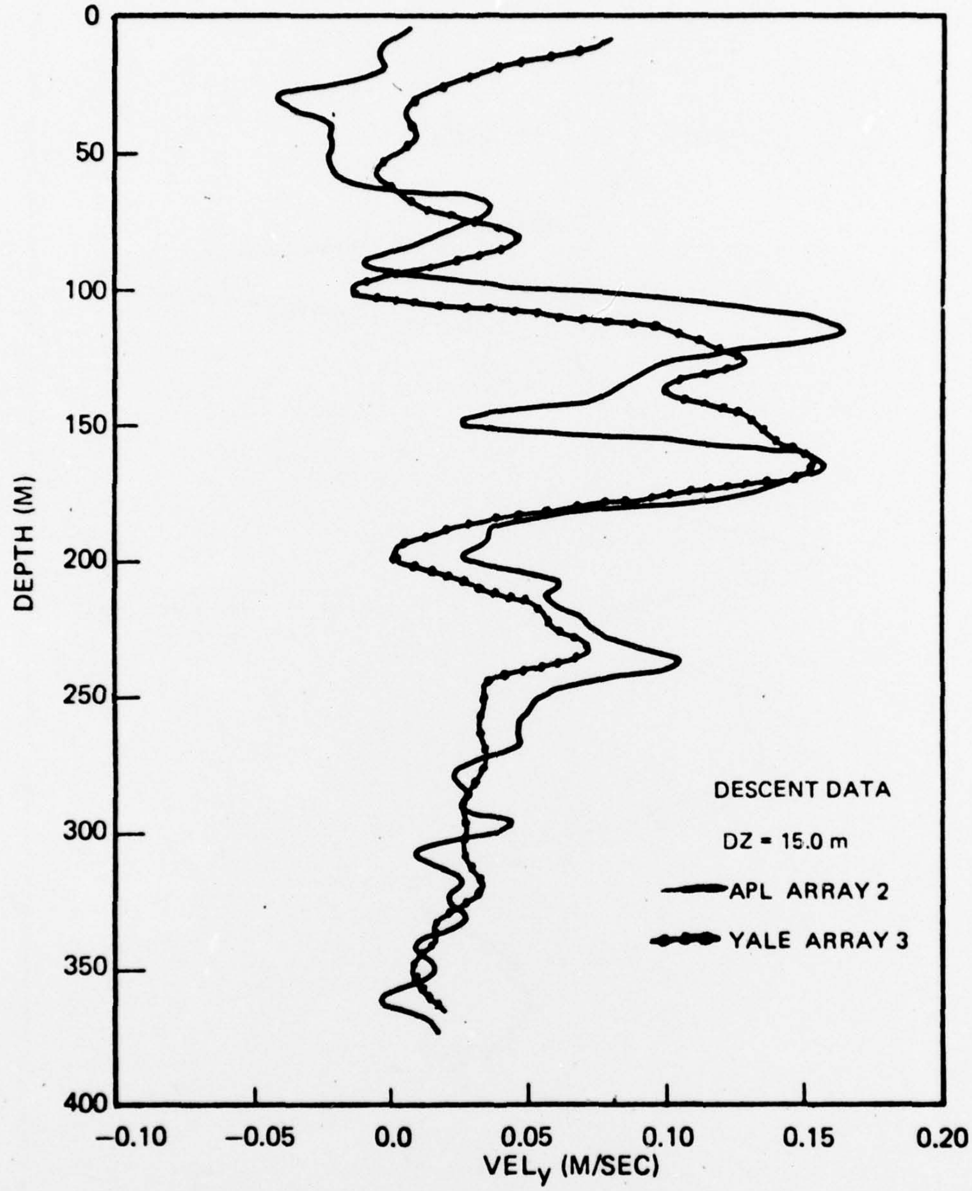

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FIGURE C4 **NORTH COMPONENT OF CURRENT FOR APL/YALE JOINT DROP 4 ON MAY 24, 1975 (HORIZONTAL SEPARATION BETWEEN PROFILERS Δr = 1400 METERS)**

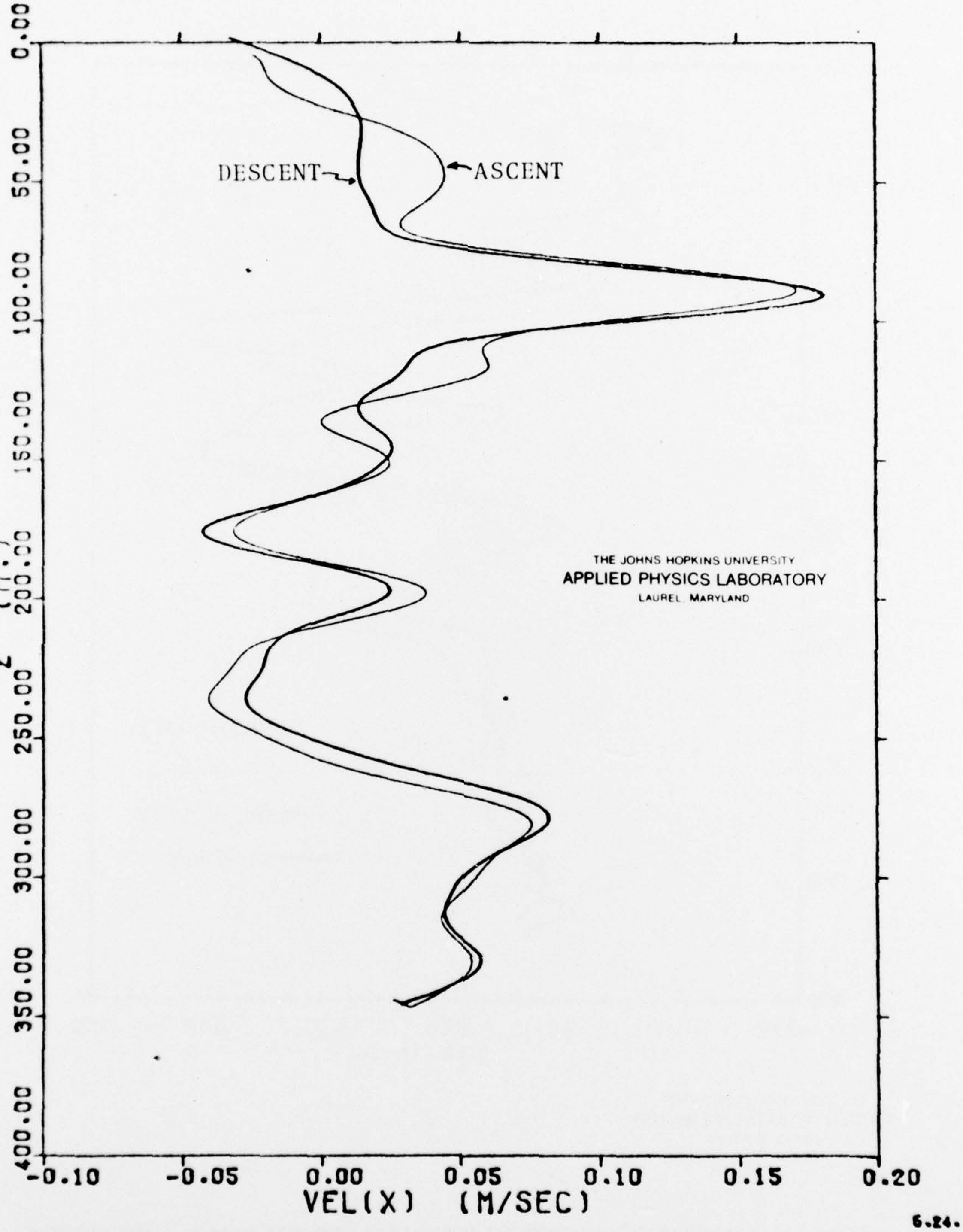


FIGURE C5 **EAST COMPONENT OF CURRENT FOR APL DROP 36J ON 9 FEB., 76 (ARRAY 2)**

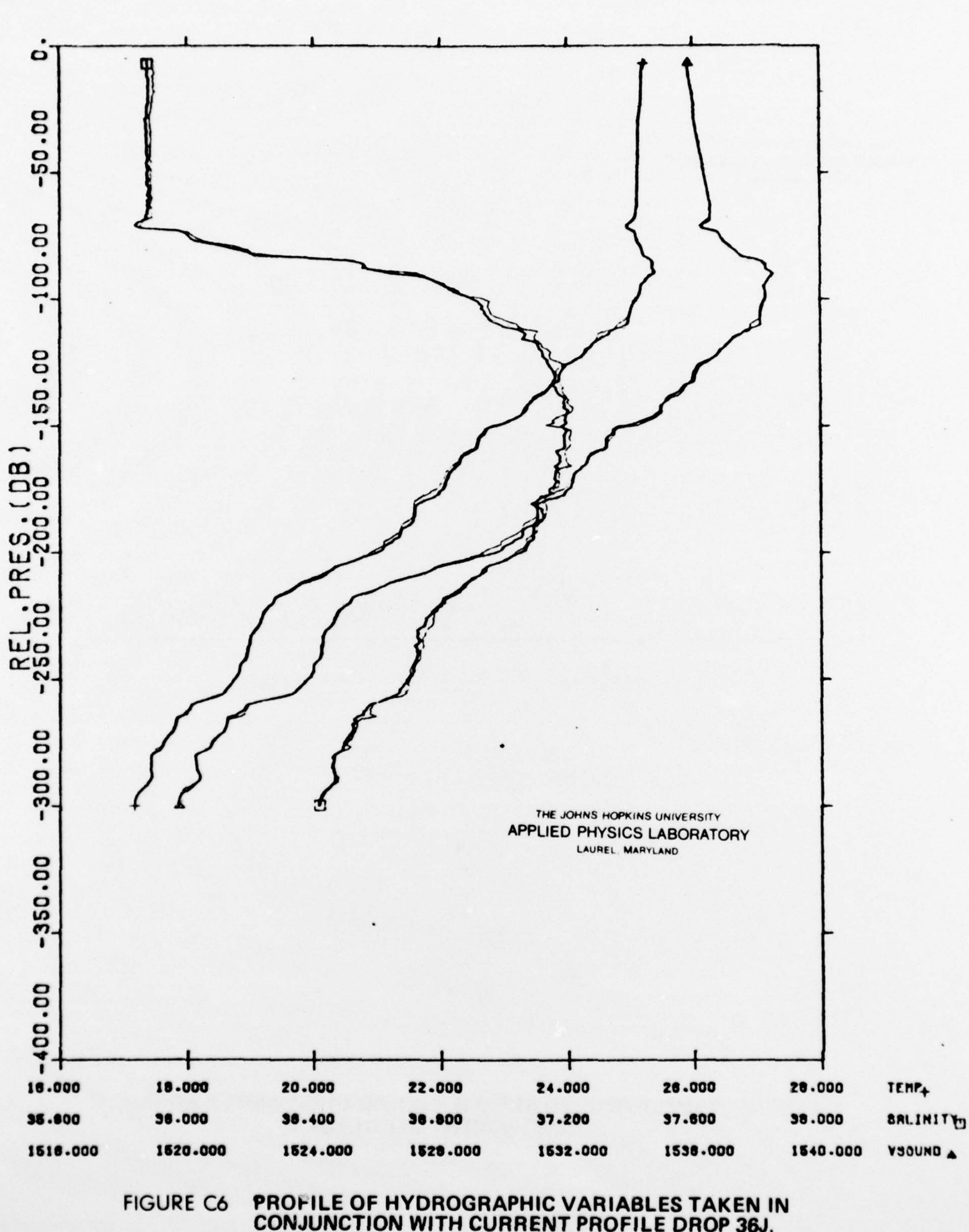


FIGURE C6 PROFILE OF HYDROGRAPHIC VARIABLES TAKEN IN CONJUNCTION WITH CURRENT PROFILE DROP 36J. (NOTE : DEPTH IN METERS ≐ RELATIVE PRESSURE IN DB)

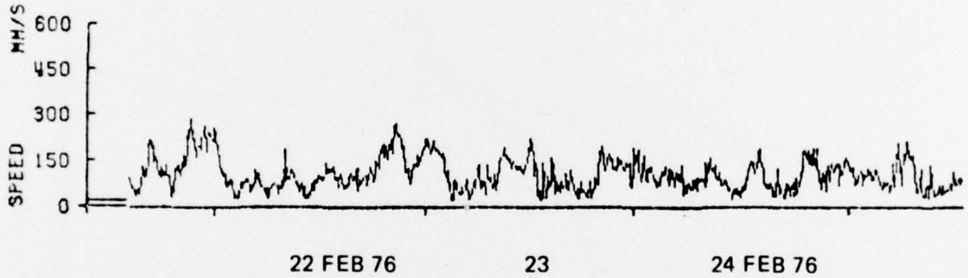
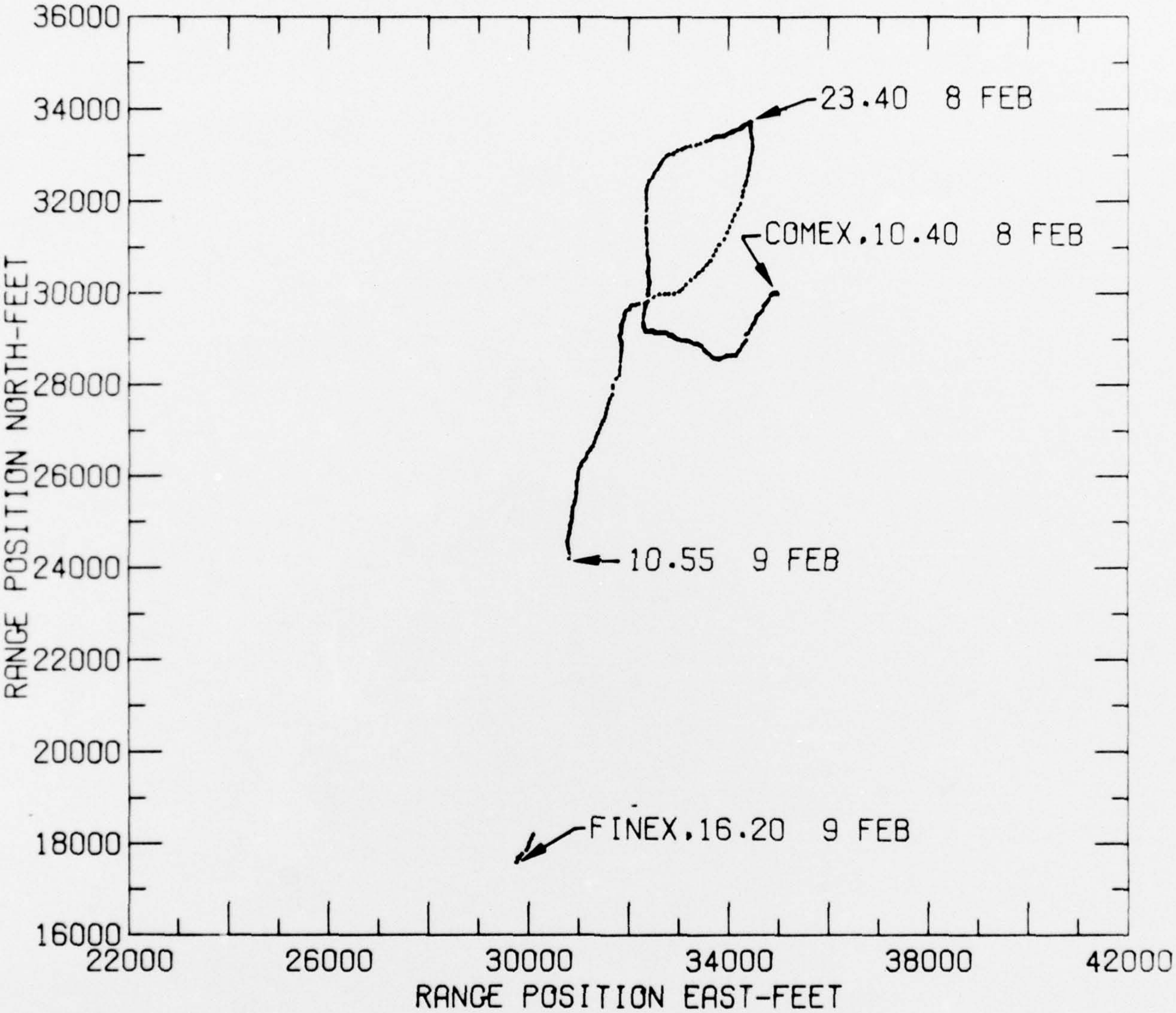


FIGURE C7 **SAMPLE RECORD FROM W.H.O.I. CURRENT METER ARRAY (INSTRUMENT DEPTH = 95 M)**



BUOY POSITION DATA 8-9 FEB

FIGURE C8